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A RADAR TEST TARGET SYSTEM

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SUMMARY

Free-flight tests have been conducted as final checks on the development of a radar test target system by the National Aeronautics and Space Administration. Inflatable spheres reflective of radar signals were chosen as the test targets because they are easily amenable to theoretical treatment and they show no variation in radar cross section with orientation to the radar beam. Two specific size spheres were used in development of the system.

The two specific versions of the radar target system which underwent testing employed a 30-inch-diameter inflatable sphere and a 12-foot-diameter inflatable sphere. In the 30-inch-diameter radar test target version of the system, a special plastic third-stage rocket was developed by the National Aeronautics and Space Administration to serve as a low radar signal reflecting target, relative to the radar signal reflecting ability of the 30-inch sphere.

Flight tests indicate that the system is capable of placing the 30-inch test target at any altitude up to 150 statute miles and a 12-foot test target up to an altitude of 80 statute miles.

INTRODUCTION

The National Aeronautics and Space Administration has recognized the need for a test target for use in research, development, and evaluation of radars, particularly those of long range. Available targets, or targets of opportunity, such as airplanes, guided missiles, and earth satellites, although representative of the objects which the radars are intended to track, are generally unsatisfactory as targets because of scintillation arising from their variation in radar cross section with orientation relative to the radar beam. A sphere reflective of radar signals is an ideal test target because its radar cross section is constant irrespective of orientation relative to the radar beam; thus, this source of scintillation is eliminated. The radar reflection characteristics of a sphere are also amenable to theoretical treatment. In addition, a sphere that is reflective of radar signals by virtue of its surface being electrically conductive is capable of reflecting radar signals of all wavelengths and is thus usable with radars of all frequencies.

In addition to the characteristics of the test target, research, development, and evaluation of radars is intimately connected with the propagation characteristics of the signal path between the radars and the target. Extensive investigation of path-propagation characteristics in the lower reaches of the earth's atmosphere have been conducted over many years by measurements between ground stations along line-of-sight
paths and paths involving reflection of the signal from the ionosphere. L
Very little research has as yet been conducted on propagation paths 3
between the ground and objects within or above the ionosphere which 2
begins at an altitude of approximately 60 statute miles. It is within 2
and above the ionosphere that long-range ballistic missiles, earth satellites, and future space vehicles operate. Accordingly, the radar test target must be capable of being placed at any desired altitude, even in space above the earth's atmosphere. This requirement dictates that it be capable of being carried aloft by means of a rocket vehicle.

A radar test target and rocket vehicle system incorporating the foregoing concepts and requirements has been devised and tested by the National Aeronautics and Space Administration. The specific versions of the system described in this report employ a 30-inch-diameter spherical test target with a three-stage rocket which is capable of carrying the test target to any altitude up to approximately 150 statute miles and a 12-foot-diameter spherical test target boosted by a two-stage vehicle up to 80 statute miles. The spherical test targets are constructed of plastic film and aluminum foil so that they may be compactly folded for carrying to altitude in the rocket vehicle, whereupon they are ejected and pneumatically erected to spherical shape. The three-stage rocket vehicle and ejection system employs a completely nonmetallic third stage designed to minimize extraneous radar signal reflections from the rocket-vehicle components in the vicinity of the 30-inch-diameter target. A two-stage system is used for the 12-foot-diameter radar test target. Because the 12-foot radar cross section is large compared with the extraneous radar cross section of the rocket-vehicle components, it is not absolutely essential to separate the sphere and the metallic vehicle components for tracking purposes. However, for better evaluation of radar units and more accurate propagation measurements, the separation of the metallic booster from the test target is advisable in the system using the 12-foot-diameter test target. Design, construction, and flight tests of the radar targets and rocket vehicles were performed by the Langley Pilotless Aircraft Research Division.

SYMBOLS

A	area based on 3.5-inch diameter, sq ft
d	diameter, ft
a	radius of spherical test targets, ft
λ	wavelength of radar unit, ft
σ	radar cross section, sq ft
C_N	normal-force coefficient, $\frac{\text{Normal force}}{qA}$
C_m	pitching-moment coefficient, $\frac{\text{Pitching moment}}{qAd}$
m	apparent visible magnitude
α	angle of attack, deg
q	dynamic pressure, lb/sq ft
h	altitude, ft
R	horizontal range, ft
V	velocity, ft/sec
M	Mach number
t	time, sec
p	roll rate, radians/sec
A_e	area of the nozzle exit, sq in.
A_t	area of the nozzle throat, sq in.
r	burning rate of propellant, in./sec
k	ratio of burning surface of propellant to throat area of nozzle
W_p	weight of propellant, lb

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W_m weight of loaded motor, lb

I_{sp} specific impulse of propellant, lb(f)-sec/lb(W)

I_{sm} specific impulse of loaded motor, lb(f)-sec/lb(W)

I total impulse of the rocket, $F\,dt$, lb(f)-sec

F thrust, lb(f)

P rocket chamber pressure, psi

Subscripts:

b burnout

av average

The f and W after units signify units of force and weight.

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TEST TARGETS AND ROCKET VEHICLES

The radar test target system is a system capable of providing spherical radar targets of any size, ranging at present from 30 inches in diameter to 12 feet in diameter. The need for different size test targets is explained from the radar curve for spheres shown in figure 1, which is reproduced from reference 1. The radar cross section is a function of the ratio of sphere radius to radar wavelength. Since present long-range radar units and those of the future operate on various frequencies, each individual radar unit might require a specific size target to maximize the radar cross section received from the back scattering of the radar wave by the target.

The basic concepts of the radar test target system, set forth in the "Introduction," have for the purpose of testing been translated into two specific designs capable of placing a 30-inch-diameter spherical target at an altitude of 150 statute miles and a 12-foot-diameter spherical target at an altitude of 80 statute miles. Both specific designs of the radar test target system make use of the same first- and second-stage booster rocket motors. The system employs the use of inflatable spheres constructed of plastic film and aluminum foil. Figure 2 shows the targets in their inflated condition. Both radar targets are compactly folded in the nose section of their respective vehicles and small tanks containing compressed gas (nitrogen) pneumatically erect them to spherical shape at the desired altitude. The aluminum foil gives the targets enough rigidity in a zero differential pressure condition to retain a spherical shape under the action of gravity; therefore, under flight conditions it is not necessary to retain the gas in either target since, once the targets have attained a spherical shape in the regions of space where the earth's atmosphere is less than 0.1 pound per square inch, they will remain spherical until encountering the denser atmosphere upon reentry at which time the external pressure becomes greater than the internal pressure of the targets. Hereafter in this report the two specific designs of the radar test target system will be referred to as the 30-inch and 12-foot radar test target systems.

30-Inch Radar Test Target System

The first version of the radar test target system employs the 30-inch-diameter radar target. This system is shown completely assembled and ready for launching in figure 3. The rocket vehicle consists of three solid-propellant stages as indicated in figure 4. A plastic third-stage rocket of low radar signal reflectivity contains the test target and is protected from aerodynamic heating by being housed within a metallic container mounted on the second stage. Upon ignition of the third stage, the container opens and releases the third-stage rocket as shown in figure 5.

In figure 6 is shown a section diagram of the container in which the third-stage rocket and the radar target are housed. The compactly folded 30-inch target is housed in the nose section of the plastic third-stage rocket. A timer releases the nose of the third stage and permits ejection of the target as shown in figure 7. The target is then pneumatically erected to spherical shape by means of a small tank of compressed gas. The specific components are outlined as follows:

Booster stages.- The first stage of the 30-inch radar test target is an M5 JATO Nike booster solid-propellant rocket motor. The second stage is a 6.25-inch-diameter solid-propellant Cajun rocket motor. A special plastic rocket motor developed by the National Aeronautics and Space Administration is used as the third and final stage. Weights of the individual parts are listed as follows:

Plastic rocket airframe, lb	2.15
Loaded rocket motor, lb	3.58
Nozzle, lb	0.51
Mahogany piston, push plate, and pressurized tank, lb	0.54
30-inch-diameter inflatable sphere, lb	0.35
Nose, lb	0.99
Cajun rocket motor, lb	171.60
Cajun fins, shroud, and fairing ring, lb	29.31
Plastic rocket container, lb	29.09

Total weight of second and third stages, lb	238.12
Total weight of first-stage Nike, lb	1,313.00
Launching weight, lb	1,550.12

Figure 8 shows the external dimensions of the plastic third-stage rocket-motor airframe. The nose is made from nylon, whereas the body cylinder is made of fiber glass and Paraplex. Similar material is used to cover the fins which are made from a foam plastic. Figure 9 shows the rocket motor case, head cap, and nozzle cut in two halves. The first two internal layers of the case and head cap are made from Bakelite BLL 3085 phenolic resin and fiber glass cloth. The two outside layers were wrapped with fiber glass tape and an epoxy resin. The nozzle, which is made from boron nitride, a nonmetallic, poor-conducting high-temperature material, is encased in a mahogany sleeve. As seen in figure 9, both the head cap and the nozzle are bonded to the interior walls of the case; thus the three parts make one integral body. The case fits inside the plastic airframe and is held by two wooden dowel pins located at the tip of the head cap and 180° apart. (Note fig. 6.) The construction and performance of the plastic motor is discussed in the appendix.

Third-stage plastic rocket container.- The third-stage plastic rocket container is made from magnesium and is used to protect the plastic rocket from atmospheric heating. Figure 10 shows the dimensions of the container which consists of three parts: base, cylinder, and cone. The base adapts to the Cajun booster and houses the timer which fires the plastic third-stage rocket, which is housed in the cylinder and cone. The cone is built in four sections. Each section is held to the other by small pins used specifically to hold the sections only in sheer. A steel nose cap screwed to a magnesium rod holds the four sections in place. Figure 11 shows the separate parts of the cone, as well as other parts of the final stage. When the plastic rocket fires, it hits the rod, expells the nose cap, separates the sections, and thus escapes from the Cajun booster.

Ejection and inflation of the 30-inch test target.- The 30-inch test target and its inflation bottle ride in the nose of the plastic rocket. The target is made from 0.0005-inch aluminum foil laminated on both sides by 0.00025-inch plastic film (Mylar). The target is 30 inches in diameter when fully inflated. The inflation tank is made from 17-4 PH (conditioned H-1000) steel and has a volume of 3.22 cubic inches. It is hydrostatically tested at 3,000 pounds per square inch. Figure 12 shows the design and dimensions of the tank.

Once the plastic rocket has separated the target from its Cajun booster, the target is ejected from the nose of this rocket. The ejection mechanism is very simple. The target and inflation bottle are housed in a piston-type mechanism made from impregnated mahogany. (Note fig. 6.) The piston rests in the nose of the rocket on a balsa disk which is held by two strips of rubber in tension, a simple slingshot.

The nylon nose is screwed to the rocket by interrupted threads. One of the two sets of threads is stationary, the other set, made from Teflon, slides toward and away from the center of the nose. (See fig. 13.) During flight, the Teflon thread is held in place by a circular cam which is part of a small clockwork timer. When the plastic rocket fires and hits the rod of the nose cone, a small nylon pin is released which sets the clock in motion. This pin is shown in figures 6 and 11. The clock turns the cam until the groove in the cam reaches the Teflon thread. At this point, the Teflon thread falls and disengages itself from the female threads of the rocket. The two positions of the Teflon thread are clearly depicted in figure 13. As the Teflon thread is disengaged, the slingshot throws off the nose and pushes the piston with its target and inflation bottle out and away from the plastic rocket as discussed earlier in this report.

The inflation bottle is activated by a trigger arm. This arm is held in place by the wall of the plastic rocket. (See fig. 6.) Once free from the rocket, the pressure from the bottle opens and locks the trigger arm and allows the gas (nitrogen) to escape into the target. The inflation bottle holds roughly 8 grams of gas when pressurized to 2,000 pounds per square inch. This quantity is adequate to inflate the target at the desired altitude.

12-Foot Radar Test Target System

The 12-foot-diameter sphere used as a radar test target produces a radar signal that is large compared with signals produced by other parts of the rocket vehicle; its size enables radar trackers to distinguish easily the reflected signal of the target from the signals produced by other vehicle components. The 12-foot radar test target system employs only two solid-propellant booster stages and a nose section. The 12-foot target is housed in the nose section held to the second-stage booster rocket by a metal band commonly referred to as a marmon band. Figure 14 shows the parts contained in the nose section and their relative positions inside the section. Figure 15 is a sketch showing the overall dimensions. A timer fires an explosive bolt which separates the marmon band, allows the nose section to separate from the second booster stage by means of a steel spring, and produces a separating force of 75 pounds. A tank of compressed gas causes ejection of the target from the nose section by means of a bellows and, in turn, inflates the target once it is outside of the nose section. When a certain differential pressure is reached in the bellows system, the test target is separated from the nose section. A two-channel-sequence telemeter is used to show that the timer fired, that nose separation from the booster stage is achieved, that the target is ejected, and that the target is separated from the nose section.

The Nike booster and Cajun solid-propellant rocket motors are the booster stages for the 12-foot radar test target system. A detailed description of the ejection and inflation of the 12-foot target can be found in reference 2 which employed a similar system differing only in the folding of the 12-foot test target, the type of telemeter, and the external shape of the nose section. Figure 16 shows the 12-foot radar test target system on the launcher ready for flight.

In order to stabilize the 12-foot radar test target system better, the fins on the second-stage Cajun booster rocket are canted 0.66° to the longitudinal axis so that the Cajun booster and the attached nose section spin up to a maximum of 800 revolutions per minute.

INSTRUMENTATION

Both the 30-inch and 12-foot radar test target systems employ an inertia timer mechanism consisting of an inertia switch and a spring-wound clock motor. The inertia switch starts the clock, which at a designated time activates a switch and closes an electrical circuit. In the case of the 30-inch system, closing the electrical circuit fires the third-stage plastic rocket, whereas, in the case of the 12-foot system, the explosive bolt and a 4.45-second delay charge in the inflation tank are fired.

In addition to the inertial timer, the 12-foot radar test target system is equipped with a two-channel sequence telemeter which transmits a continuous signal to the ground receiving station. Change in frequency of the transmitted signal indicates that one of a prescribed number of events has taken place. One channel notes a change in frequency produced when the inertia timer closes the electrical circuit. The second channel notes a change in frequency when two microswitches open at nose separation, another change when the release mechanism (ref. 2) opens a switch at target ejection, and a final shift in frequency when the release mechanism closes at target separation from the nose section.

Ground equipment used for tracking both systems from the NASA Wallops Station includes the NASA SCR-584, the AFMTC Mod. II, and RCA FPS-16 tracking radars. These radars skin-track the vehicles and determine slant range, azimuth, and elevation angle from which altitude, horizontal range, and flight-path angle can be calculated. A radiosonde, employing a balloon is launched prior to the time of flight. This radiosonde provides measurements of static pressure, static temperature, balloon azimuth, and balloon elevation up to altitudes of approximately 85,000 feet. Wind velocity, wind direction, and speed of sound are calculated from these data. From velocity measurements calculated from data obtained with a CW Doppler radar unit, the Mach number is obtained.

In order to track the targets photographically, twilight firings are scheduled to allow the targets to appear as bright objects against the evening sky. Along with high-speed tracking cameras, box cameras are used. These cameras take time exposures of the sky in the area that preflight calculations indicate the targets will be visible. Six five-power moonwatch telescopes covering an azimuth range of 22° and an elevation range of 32° are used for visual tracking.

PRELIMINARY TESTS

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Extensive testing on all mechanical parts of both the 30-inch and 12-foot radar test target systems was carried out prior to flight tests. Both systems were subjected to simulated-flight conditions up to altitudes of 150,000 feet in two vacuum facilities located at the Langley Research Center.

Tests on the 30-Inch Radar Test Target System

Preliminary tests of the 30-inch radar test target system were concentrated in four main areas. Each area is discussed as follows:

Target ejection and inflation.- The complete ejection and inflation of the 30-inch target was conducted in a 56-inch-diameter cylindrical vacuum facility to prove that the target would eject and inflate from its compactly folded condition in the nose of the plastic third-stage rocket. The plastic rocket was placed upright in the vacuum tank. A solenoid located at the top of the tank lets fall a metallic weight which activates the timer in the nose of the plastic rocket. On a number of consecutive tests the nose was successfully thrown off, the target ejected, and complete inflation achieved. Since the model was upright in the vacuum tank, the ejection mechanism had to work against the force of gravity. Since the dynamic pressure, for all practical purposes, is zero under flight conditions at target ejection, the force on the nose should be less than the force it worked against in the vacuum tank.

Third-stage plastic rocket container.- The expulsion of the nose cone of the third-stage plastic rocket container was tested at NASA Wallops Station by ground firing the plastic rocket from its enclosed position in the container. The four sections of the nose cone were completely separated and thus the plastic rocket was allowed to escape from its cylindrical container.

Plastic rocket airframe.- In order to determine the stability of the plastic rocket airframe, tests were conducted in the Langley Unitary Plan wind tunnel. Normal-force and pitching-moment coefficients were obtained from three different tests at a Mach number of 4.65. Two tests were made at a dynamic pressure q of 76 pounds per square foot. On the first test the fins coincided with the axes of the test chamber. For the second test the fins were rotated to give angles of 45° with the axes of the test chamber. A final test was made at a dynamic pressure q of 265 pounds per square foot with the fins 45° to the reference axis. All three tests were run through angles of attack varying from -10° to 10°. Figure 17 shows the variation of normal-force and pitching-moment coefficients with angle of attack for the different conditions. The center of gravity of the plastic rocket was used as the reference center for these curves.

Plastic rocket motor.- The preliminary testing of the special NASA plastic rocket motor is discussed in the appendix.

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Tests on the 12-Foot Radar Test Target System

Extensive testing of each feature of the 12-foot radar test target system was conducted before testing the system as an integrated unit. Atmospheric as well as vacuum tests in the 41-foot-diameter vacuum sphere at the Langley Research Center were conducted. The areas of testing are discussed in the following paragraphs.

Vacuum tests.- Extensive tests in the Langley 41-foot-diameter vacuum sphere simulating altitudes up to 150,000 feet were conducted. Since the flight model was to be spinning in order to provide better stability and performance, the test package was spun up to 800 revolutions per minute by an electric motor located at the top of the vacuum tank. On each test the same sequence of events (nose separation, target ejection, target inflation, and target separation), which would take place on the flight test, were thoroughly checked. It was found that the 12-foot target took to the order of 30 seconds to erect pneumatically after ejection and to the order of 3 minutes to separate from the nose section. In order to complete the vacuum tests the telemeter section was installed on the test package in the vacuum tank. The telemeter transmitted a signal through an antenna on the inside of the tank to a transmitter on the outside of the tank which forwarded the signal to the ground station at the Langley Instrument Research Division building. In this way the telemeter was checked out under spinning and vacuum conditions. Figure 18 is a sequence of photographs showing the 12-foot target eject and inflate from its spinning condition inside the vacuum tank.

Bench test.- Prior to the test of the telemeter in the vacuum tank, a bench test of the whole system was conducted by the Langley Instrument Research Division. The entire system was checked in this test with the exception of spin and complete target inflation. Since the separation of the target from the nose section depends only on the differential pressure in the bellows system (ref. 2), the extent of inflation in the target has no consequence on the target's separation from the nose. An important feature of the bench test was to show that the ejection of the target would work under atmospheric conditions where the restraining forces are much higher than what the system would experience in a near vacuum.

FLIGHT TESTS

Both the 30-inch and 12-foot radar test target systems were fired in the evening in order that they would be visible. In order to insure good visible tracking for a reasonable duration of time, which would be to the order of 3 to 5 minutes, two conditions must be considered. In order to maximize the apparent visual magnitude of the target, a large differential magnitude between the target and sky background is desirable. This requirement indicates that the later the targets are fired after sunset the higher the magnitude differential will be. Since the target is a reflector, it must get into the sunlight before it is visible to observers on the ground. As the sun continues to fall more and more below the observers' horizon, the higher the target must be to get into the light of the sun. Since the trajectories of both targets are fixed, a time must be found after sunset when the sky is dark enough and the sunlight line low enough to render 3 to 5 minutes of visible observing time. The firing time for the 12-foot radar test target system was chosen as 30 minutes after sunset, whereas a higher altitude and a smaller magnitude made the firing time for the 30-inch system 47 minutes after sunset. Figure 19 shows the calculated altitude of the sunlight-darkness line as a function of time for both radar test target systems. Visible time of observation can be read from the altitude-time curves in this same figure.

The 30-Inch Radar Test Target System

The 30-inch system was launched 47 minutes after sunset on an azimuth of 110° and at an elevation angle of 75° from the horizontal. The first stage boosted the vehicle to an altitude of 5,000 feet and then drag separated from the second-stage Cajun booster. After a 15-second coasting period the Cajun sustainer fired; thus, the model was given a velocity of 6,600 feet per second at an altitude of 48,000 feet. After a 13-second coasting period, at an altitude of 114,000 feet and an estimated velocity of 5,000 feet per second, the third-stage plastic rocket fired out of its container adapted to the Cajun booster. CW Doppler velocimeter data was obtained up to 25 seconds. Figure 20 is a plot of velocity against time for the 30-inch-diameter system. Velocities for the plastic rocket and target after 25 seconds were theoretically calculated.

The 12-Foot Radar Test Target System

The 12-foot system was launched 30 minutes after sunset on an azimuth of 100° and at an elevation angle from the horizontal of 80°. The first-stage Nike booster boosted the system to an altitude of 5,000 feet and a velocity of 3,240 feet per second and then drag separated from the second-stage booster. After a coasting period of nearly 20 seconds, the Cajun booster fired and thus gave the system an estimated velocity of 5,650 feet per second. Velocity data from the CW Doppler radar unit were good up to 17 seconds. Velocities from this point on were mathematically deduced from the tracking radar data up to 100 seconds and were theoretically calculated from this point on. A time history of velocity and Mach number are shown in figure 21.

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RESULTS AND ANALYSIS

Results and analysis of the data from flight tests of the two specific versions of a radar test target system indicate that both versions of the system are adequate for placing the radar targets at the desired altitude. Theoretical treatment of preflight calculations proved to be extremely accurate, and predicted altitudes and velocities were attained.

Only two specific versions of the radar test target system have been tested; however, targets other than those with diameters of 30 inches or 12 feet can be easily developed for operational use. Since maximum electron density in the ionospheric regions occurs at altitudes above 600,000 feet, it could be of some advantage to increase the altitude of the targets in order to obtain radar propagation measurements. The rocket boosters employed in the radar test target system are easily adaptable to further staging; thus, increasing the altitude of the system only means adding additional stages to the existing boosters of the system.

30-Inch Radar Test Target Flight Results

Between 90 and 100 seconds from zero time, the target appeared in the sky as a bright object on an azimuth of 114° and at an elevation angle of 67°. The apparent magnitude of the target was that of the North Star, roughly second magnitude. The apparent magnitude of the 30-inch test target plotted against time is given in figure 22. This curve assumes total specular deflection. (See ref. 3.) The path of the target was photographed by box cameras and followed visually by observers using the unaided eye as well as moonwatch telescopes. The path of the target is shown against the background of the stars in figure 23. This is a 3-minute time exposure taken from 1 to 4 minutes from zero time. The bright star at the very bottom of the photograph is Arcturus, a first-magnitude star. The bright star at the right and above Arcturus is Muphrid, a third-magnitude star.

The AFMTC Mod. II radar tracked the Cajun booster up to 45 seconds. Data at 35 seconds clearly show that the nose cone was expelled; that is, the plastic rocket fired. Altitude as a function of time for the plastic rocket and test target is taken from the AFMTC Mod. II data up to 35 seconds and theoretically calculated from this time on. For the Cajun booster theoretical calculations were used from 45 seconds on for 0° and 90° angle-of-attack attitudes. These are seen in figure 24. Altitude and horizontal range trajectories are shown in figure 25.

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30-Inch Radar Test Target Flight Analysis

The AFMTC Mod. II radar showed that the plastic rocket fired, but the radar was unable to detect the rocket itself. Although this result is not conclusive, it indicates that the plastic rocket is a very poor radar target. This, of course, is the purpose of the rocket. Even though the radars were unable to track the plastic rocket, there is information which indicates that the preflight calculations of performance and stability are relatively accurate. The target vehicle was fired on an azimuth of 110° but early in flight it shifted to an azimuth of 114°. The target appeared in the sky on a 114° azimuth. Duration of visible observation indicates that the altitude was in the vicinity of that which was predicted. These two facts indicate that the plastic rocket functioned satisfactorily.

12-Foot Radar Test Target Flight Results

The SCR-584 and RCA FPS-16 radars tracked the 12-foot target vehicle for 100 seconds to an altitude of 300,000 feet. The RCA FPS-16 radar furnished tracking data from 1,420 seconds at an altitude of 60,000 feet to 2,880 seconds down to an altitude of 20,000 feet. A time history of altitude is shown in figure 26. Altitude as a function of horizontal range is shown in figure 27.

The two-channel sequence telemeter record was good up until the nose section impacted with the ocean. All four frequency changes were noted on the record. The 120-second timer fired at 119.97 seconds; nose separation occurred 1.43 seconds later. At 125.64 seconds from launch time, the target ejected and began inflation; and 172.10 seconds from ejection the test target separated from the nose section. This timing is to the order obtained in the final preflight vacuum test. Because signal strength was recorded on the telemeter record, it was possible to determine the roll rate of the spinning model by counting the cycles over a time interval produced by antenna phase. A maximum roll rate of 67.3 radians per second was recorded at 29 seconds. At nose separation and target ejection the roll rate was 61.7 radians per second. A time history of roll rate is shown in figure 28. Figure 29 is a time history of absolute visual magnitude for the 12-foot target when specular deflection is assumed.

12-Foot Radar Test Target Flight Analysis

Because of the duration of tracking time and the extremely slow L
rate of descent, it is certain that the RCA FPS-16 tracking radar was 3
tracking the 12-foot target on the last part of its flight. The telemeter 2
record indicates that the nose section separated from the target at 2
297.74 seconds from zero time and theoretical calculations indicate an altitude of 150,000 feet for this time. The telemeter indicated splash of the nose section at 492 seconds from zero time, whereas the RCA FPS-16 was able to continue tracking the target at 1,420 seconds from zero time at an altitude of 60,000 feet. Splash of the Cajun booster probably occurred at nearly the same time as the nose section.

CONCLUDING REMARKS

Free-flight tests conducted with two specific versions of a radar test target system indicate that both versions of the system operated satisfactorily. One version of the system consisting of a 30-inch-diameter spherical test target and a special low radar-signal-reflecting plastic third-stage rocket reached a maximum altitude of approximately 150 statute miles. A second version of the system employing a 12-foot-diameter spherical test target reached a maximum altitude of 80 statute miles.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., August 13, 1959.

APPENDIX A

THE PLASTIC ROCKET MOTOR

Description of Motor

The third-stage plastic rocket motor was designed to impart a velocity increment of approximately 1,000 feet per second to the third-stage system. Based on the estimated payload weight of 4.5 pounds and a propellant-weight fraction of 50 percent for the plastic rocket motor, preliminary calculations indicated that a motor weighing 4.5 pounds with an impulse of about 400 lb(f)-sec would be necessary to impart the required velocity. These calculations took into account such factors as the drag, stability, and performance of both the third-stage system and the entire Nike—Cajun—plastic-rocket vehicle. In order to keep the third-stage acceleration below 30g, a burning time of at least 2 to 3 seconds was required.

In addition, calculations indicated that an outside diameter for the rocket of about 3.25 inches was optimum in compromising between stability and the minimum package for the sphere and associated ejection apparatus.

In order to avoid extensive investigation in regard to the optimum ratio of case weight to strength, it was decided to design the case to withstand an internal pressure in excess of 600 pounds per square inch with the operating chamber pressure to be about 400 pounds per square inch. The wall thickness was set at 0.15 inch with an inside diameter of 3.00 inches.

A progressive five-point star charge design was chosen for the cavity form. (See fig. 30.) The progressiveness was partially compensated for by not inhibiting the rear face of the propellant grain.

In order to achieve the 2- to 3-second burning time with the 0.67-inch web, the minimum distance the propellant burns normal to the burning surface, Thiokol T-13E1 propellant was selected. Inasmuch as the program was limited in the number of motors needed, it was decided to cast the propellant in the propellant processing facility of the Langley Pilotless Aircraft Research Division. Previous data obtained from 3.25-inch test motors showed that differences existed in the ballistic characteristics of PARD cast T-13E1 and the Thiokol specifications. These differences are due to the lack of close quality control in the oxidizer grinding operation. Plots of both the k value (ratio of burning surface area to throat area) and r (burning rate) as functions of pressure for the PARD cast T-13E1, from which the plastic rocket was designed, are shown in figure 31.

Based on an average chamber pressure of 400 pounds per square inch, the 3-inch grain diameter, the required impulse of 400 lb(f)-sec, and optimum expansion at sea level, the design values for the plastic rocket are shown in table I.

As the motor would be operating at an altitude of 70 to 120 statute miles, a very high expansion rate A_e/A_t would be required. Since the nozzle was to be bonded inside the case, the maximum exit diameter without a flare would be approximately the inside diameter of the case. In order to avoid having both a sea-level nozzle and an altitude nozzle designed and fabricated, it was decided to conduct the static tests with the altitude nozzle. Based on an exit diameter of 2.5 inches, the performance values at sea level are shown in table I. Percent sliver loss is defined as the percent of propellant unburned at web burn through.

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Static Testing of Plastic Rocket Motor

The first static test of the plastic rocket motor, using a molded silicone nozzle and a magnesium-potassium perchlorate "shot-gun" type igniter for simplicity, had a progressive pressure curve which resulted in the nozzle breaking up at 1.1 seconds after a 2.7-second hangfire. After the second test, it was discovered that the progressivity was due to the rear end of the grain being inhibited. Hence, the length of the burning surface increased as the front end of the grain burned forward, the rear end remaining stationary.

From this first test, the erroneous conclusion was drawn in regard to an abnormal progressivity of the burning surface of the grain configuration. Therefore, a higher average burning surface was assumed, and the nozzle throat diameter of the second rocket was increased to compensate for it. As a result, the pressure time history for the second test (fig. 32) is low. The boron nitride nozzle and a higher weight magnesium-potassium perchlorate shot-gun igniter were used in this test. There was a 2.7-second hangfire.

After the hangfire, the shot-gun type igniter was discarded and a "jelly-roll" type igniter was used for all subsequent firings. In order to avoid any more wide variance in the performance of the rocket due to the poor quality control of the propellant processing, it was decided that in the future the throat of the nozzle would not be machined until after the ballistic characteristics of the propellant batch involved were determined. Hence, motor 3 was fired on this basis. Results are shown in figure 33. There was a 2.2-second hangfire.

After the third test, the rocket was considered to be acceptable in regard to internal ballistics. However, as any delay in ignition at an altitude of 70 statute miles could result in a misfire, a much more potent jelly-roll igniter was designed to ignite the rocket adequately. The fourth plastic rocket was flight tested at NASA Wallops Station as a complete third-stage system with no appreciable ignition delay.

Based on the pressure and thrust time histories of the rocket in the third test, the theoretical performance of the plastic rocket at an altitude of 70 statute miles is shown in table I.

REFERENCES

1. Siegert, A. J. F., Ridenour, L. N., and Johnson, M. H.: Properties of Radar Targets. Radar System Engineering, Louis N. Ridenour, ed., Ch. 3, McGraw-Hill Book Co., Inc., 1947.

2. Kehlet, Alan B., and Patterson, Herbert G.: Free-Flight Test of a Technique for Inflating an NASA 12-foot-Diameter Sphere at High Altitudes. NASA MEMO 2-5-59L, 1959.

3. Zirker, J. B., Whipple, F. L., and Davis, R. J.: Time Available for the Optical Observation of an Earth Satellite. Scientific Uses of Earth Satellites, James A. Van Allen, ed., Univ. of Michigan Press (Ann Arbor), c.1956, pp. 23-28.

TABLE I.- CALCULATED AND EXPERIMENTAL PERFORMANCE VALUES OF THE PLASTIC ROCKET MOTOR

	Calculated performance at sea level for -		Experimental performance at sea level (test 3) for -	Calculated performance at altitude (test 3) for -
	Optimum expansion ratio	Expansion ratio, 17.4	Expansion ratio, 17.4	Expansion ratio, 17.4
I	456	373	349	529
I_b	400	328	296	449
t_b	2.48	2.48	3.10	3.10
$F_{av,b}$	161	132	96	145
$P_{av,b}$	400	400	413	413
W_p	2.44	2.44	2.31	2.31
W_m	4.88	4.88	4.17	4.17
I_{sp}	187	153	151	229
I_{sm}	93	76	84	127
Sliver loss, percent	12.1	12.1	15.2	15.2

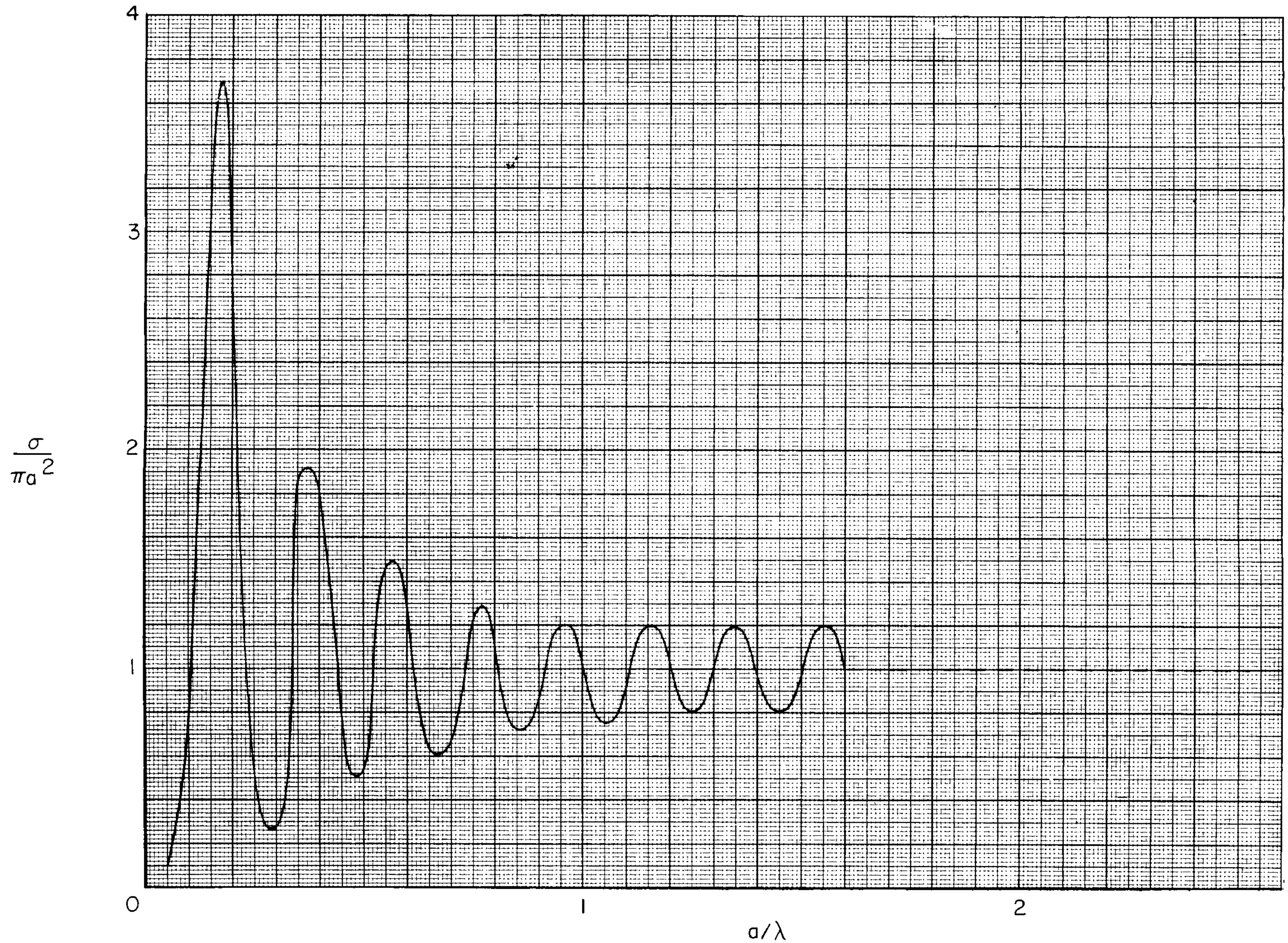


Figure 1.- Radar scattering of a plane wave by a sphere.

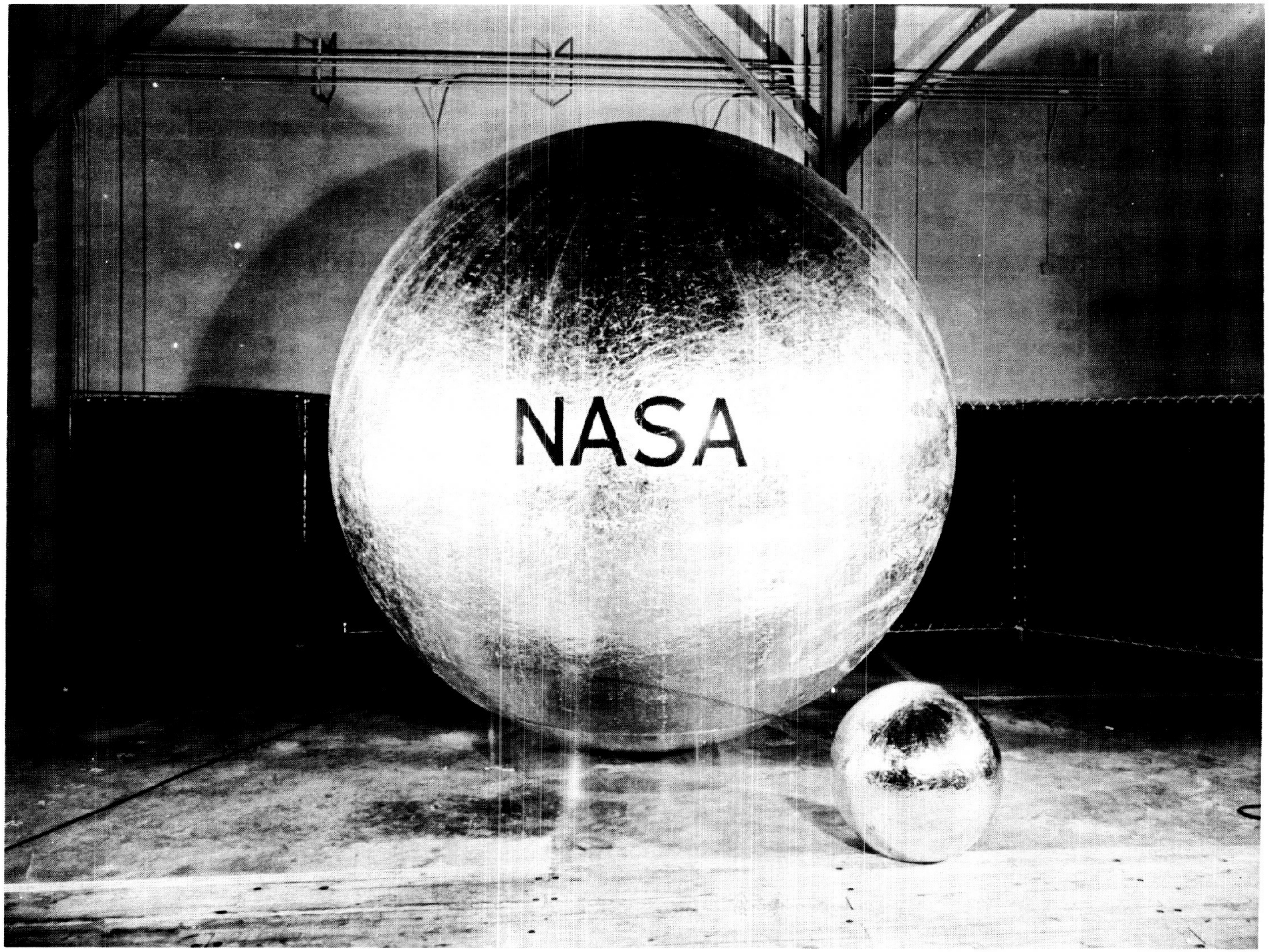
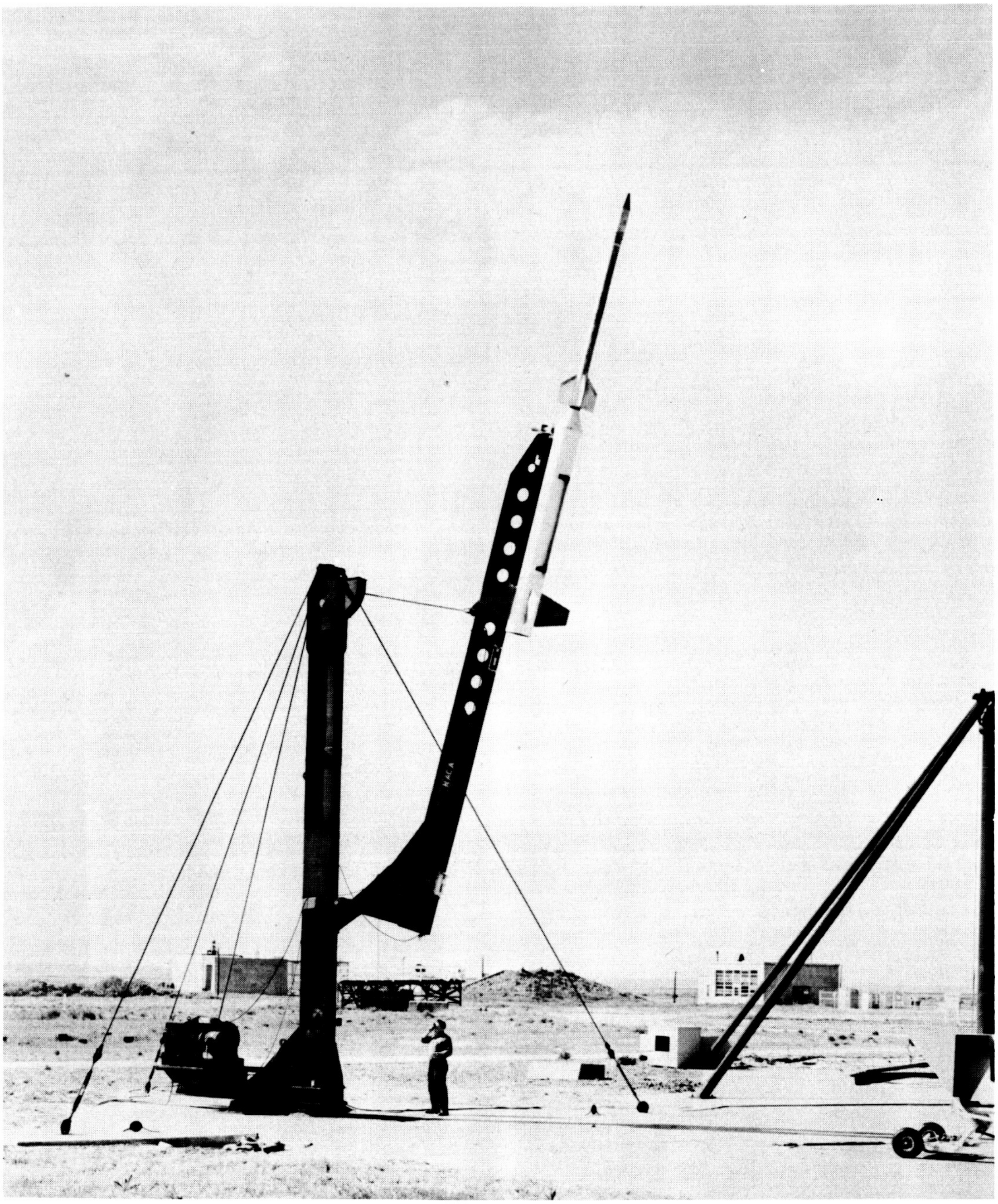


Figure 2.- NASA 30-inch and 12-foot radar test targets. L-58-1076a



L-58-2369

Figure 3.- The 30-inch radar test target system assembled for launching.

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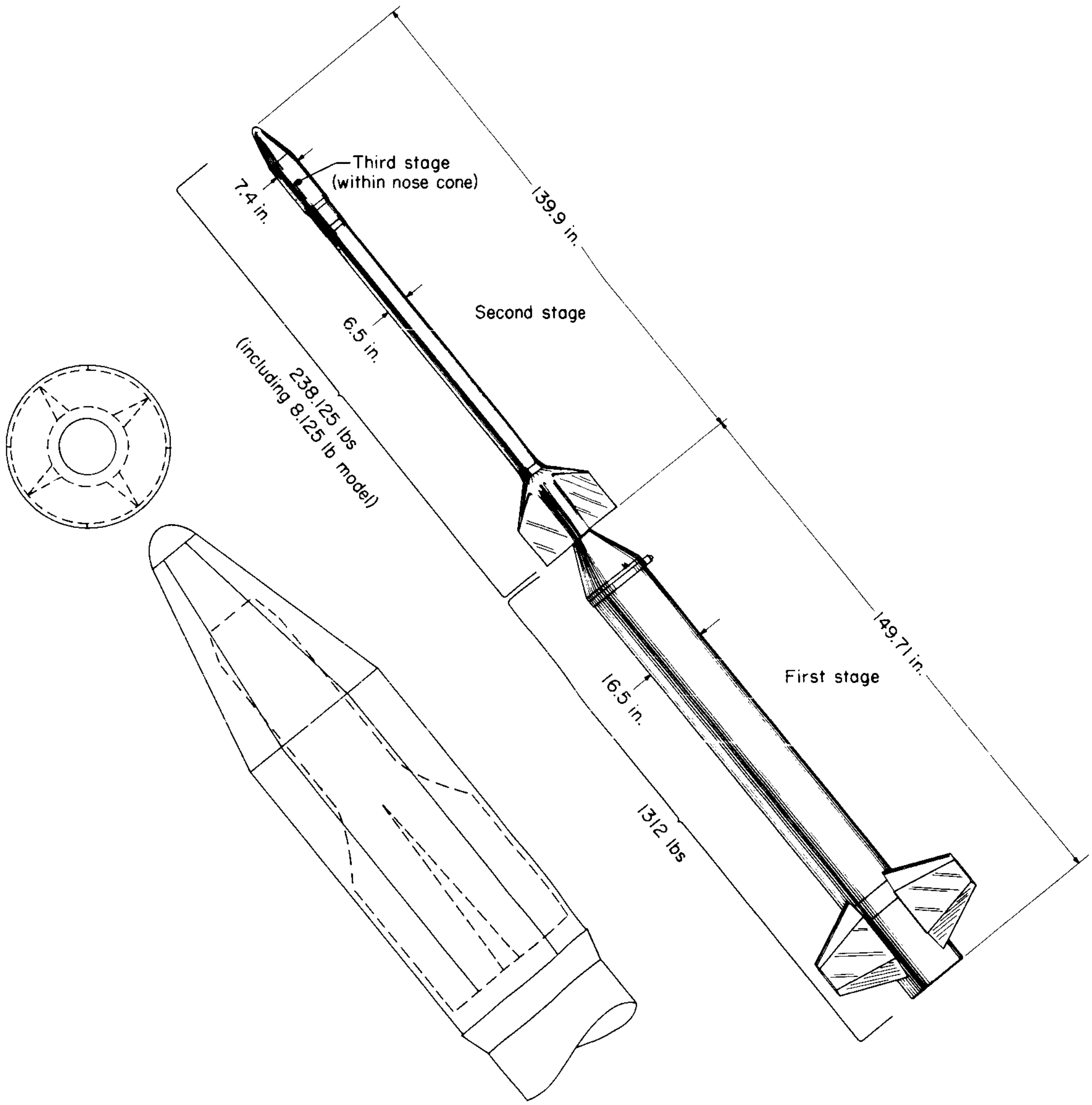

Figure 4.- General description of the 30-inch radar test target system.

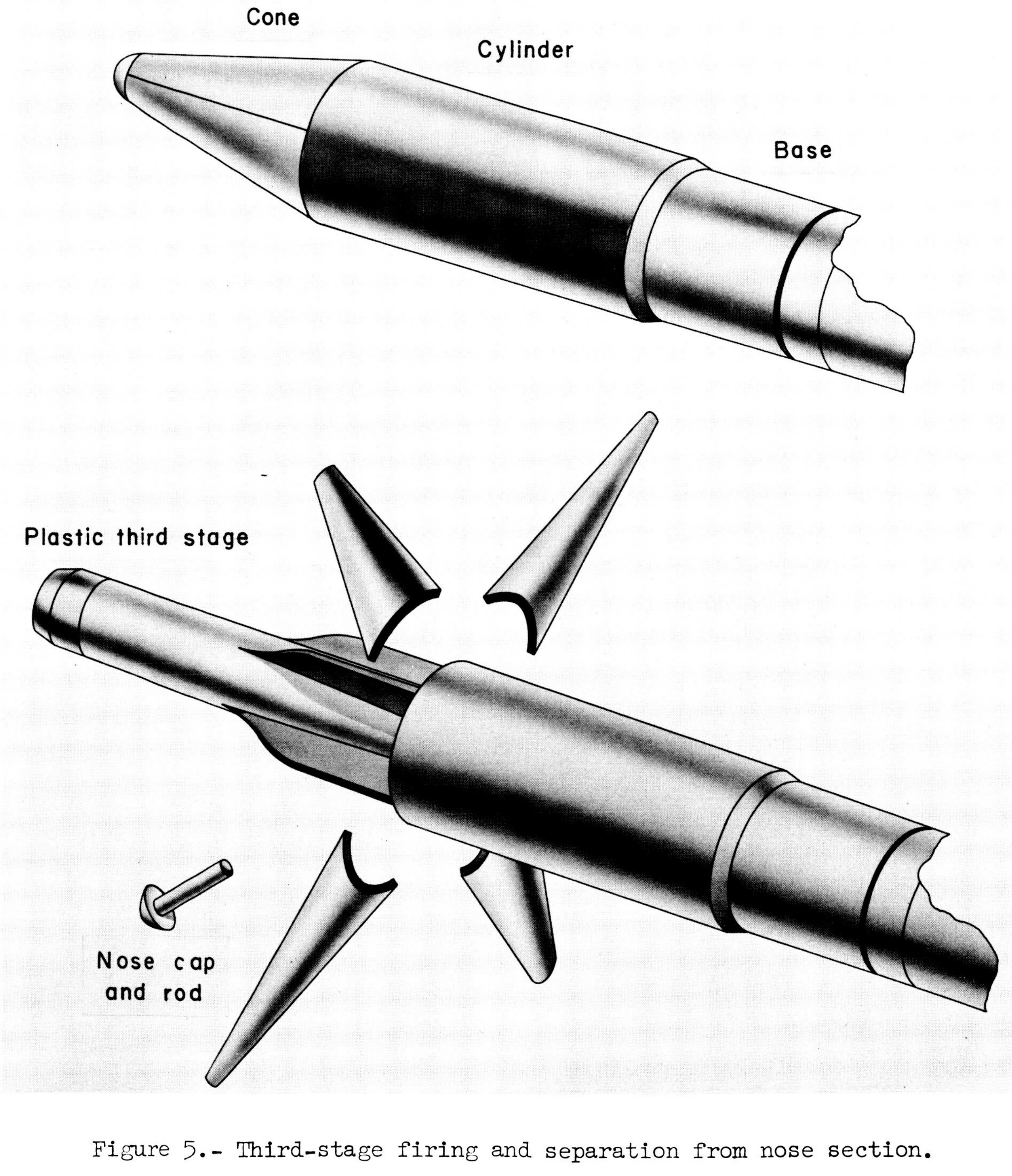

Figure 5.- Third-stage firing and separation from nose section.

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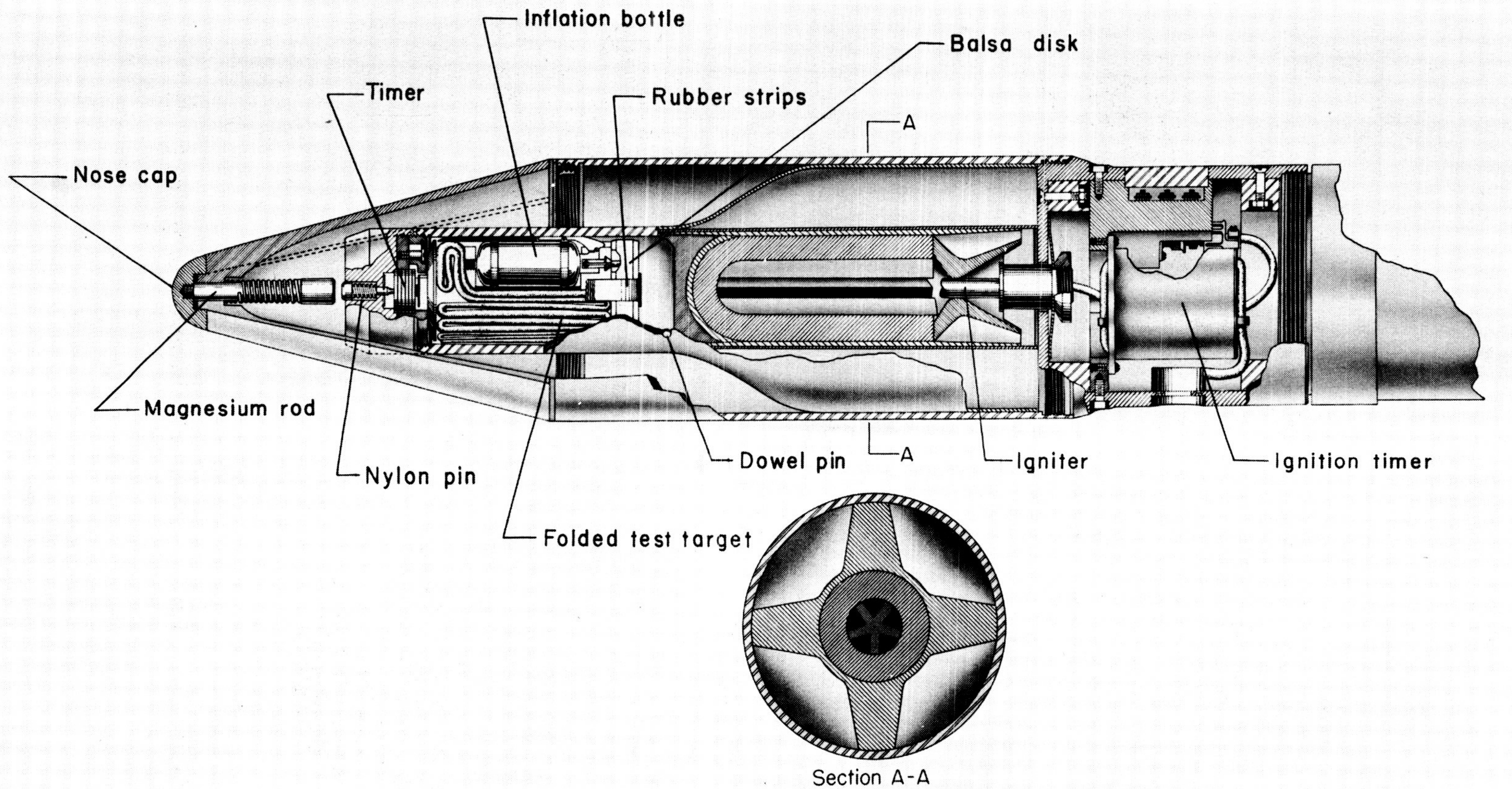

Figure 6.- Internal structure of third-stage rocket and target-release mechanism.

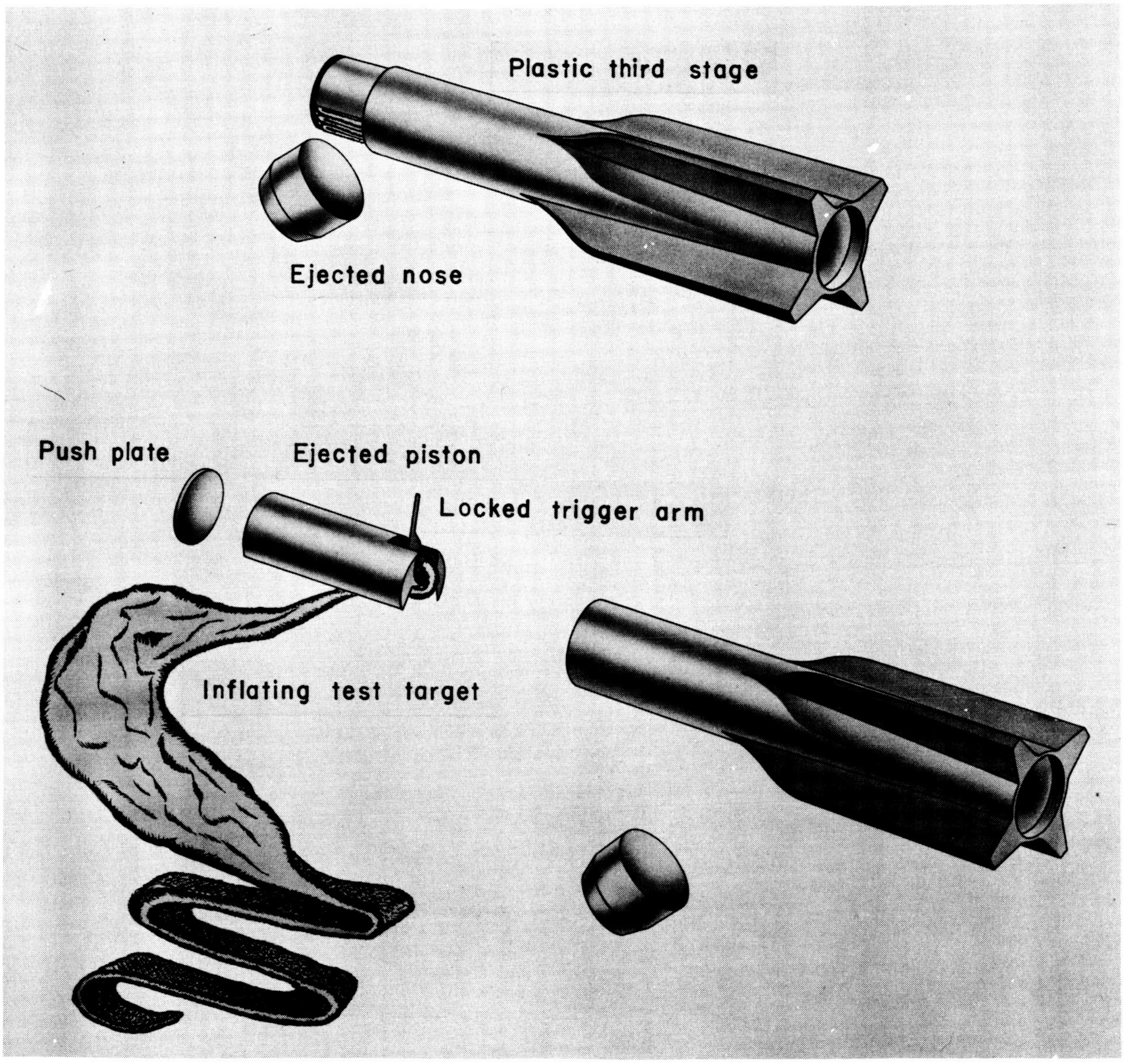

Figure 7.- Test target ejection from plastic third stage.

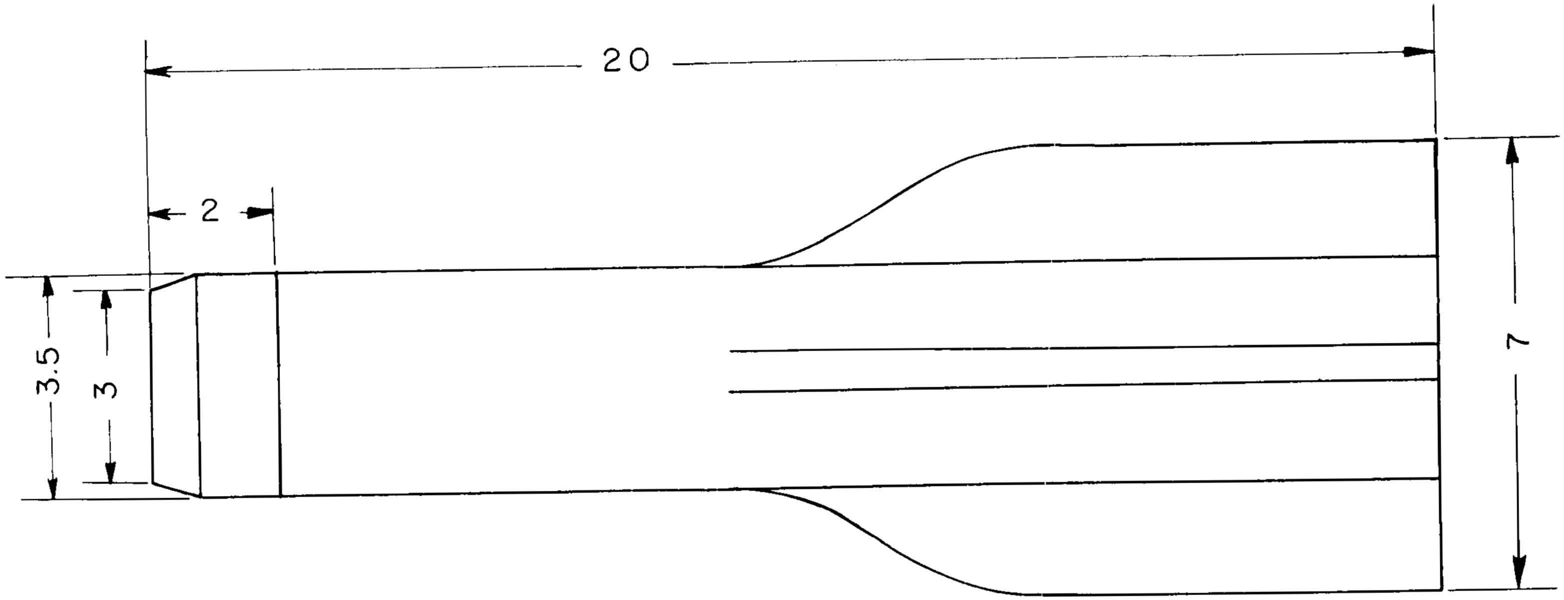

Figure 8.- External dimensions of the plastic rocket. All dimensions are in inches.

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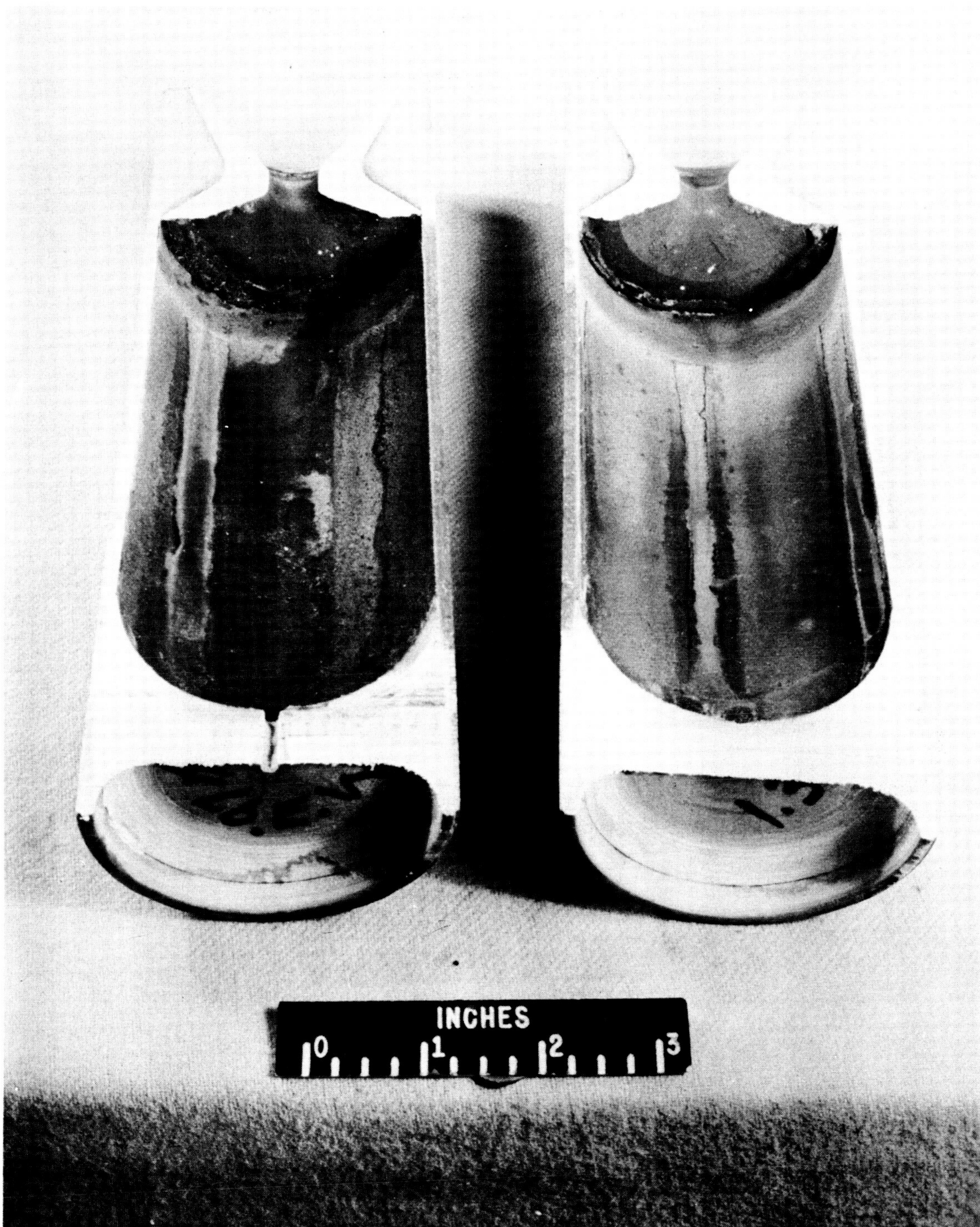


Figure 9.- View of plastic rocket case, head cap, and nozzle. L-58-95

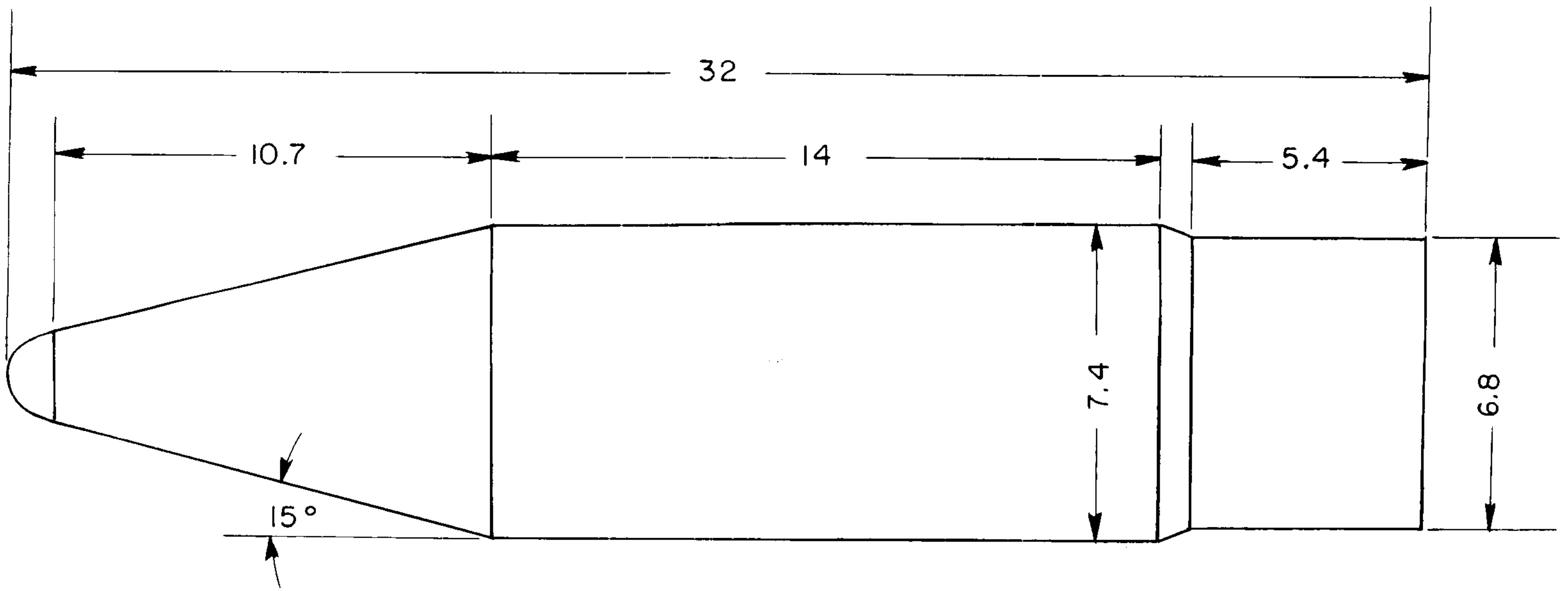


Figure 10.- External dimensions of the third-stage plastic rocket container. All dimensions are in inches.

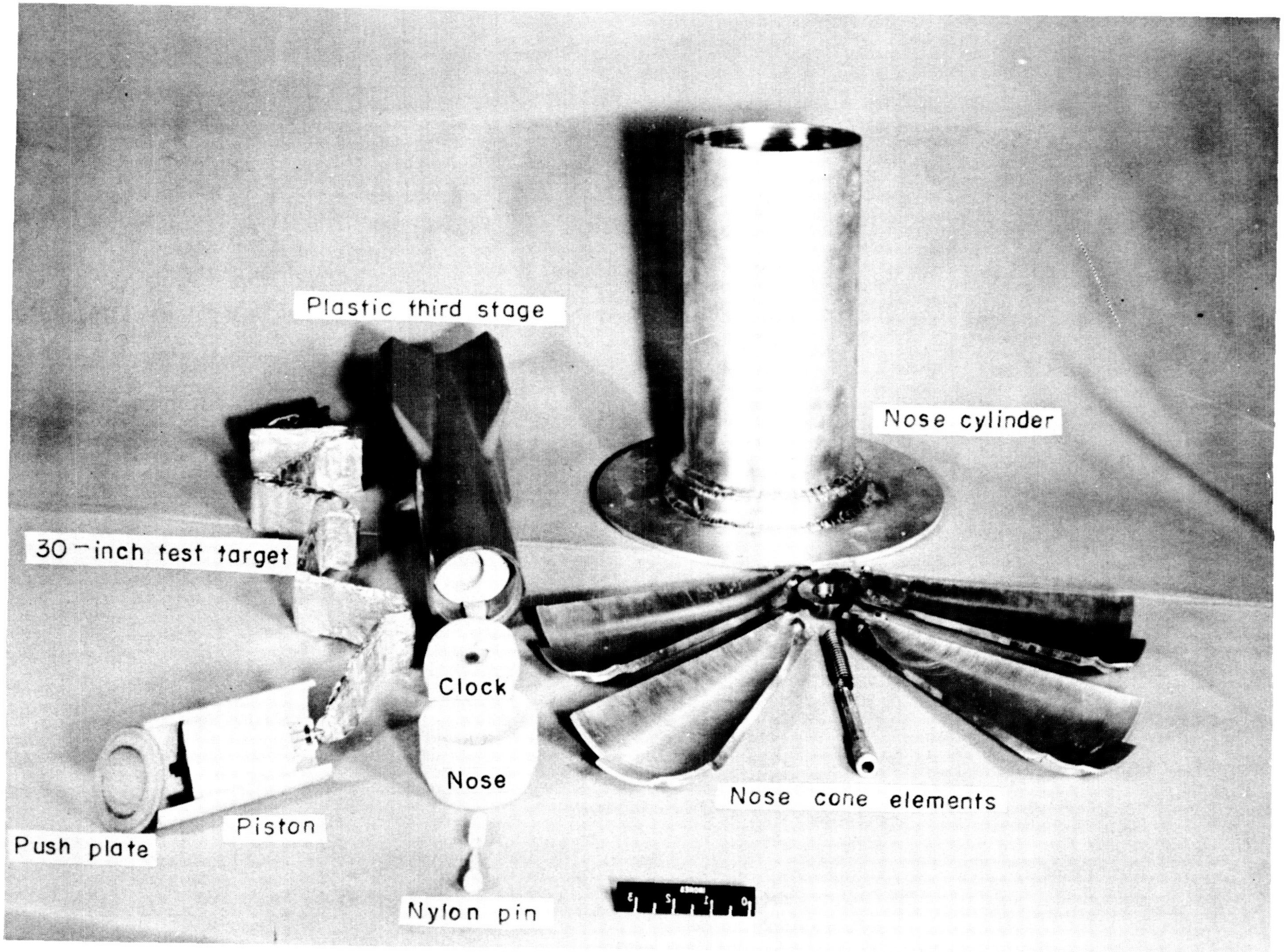


Figure 11.- Component parts of nose section. L-58-835.1

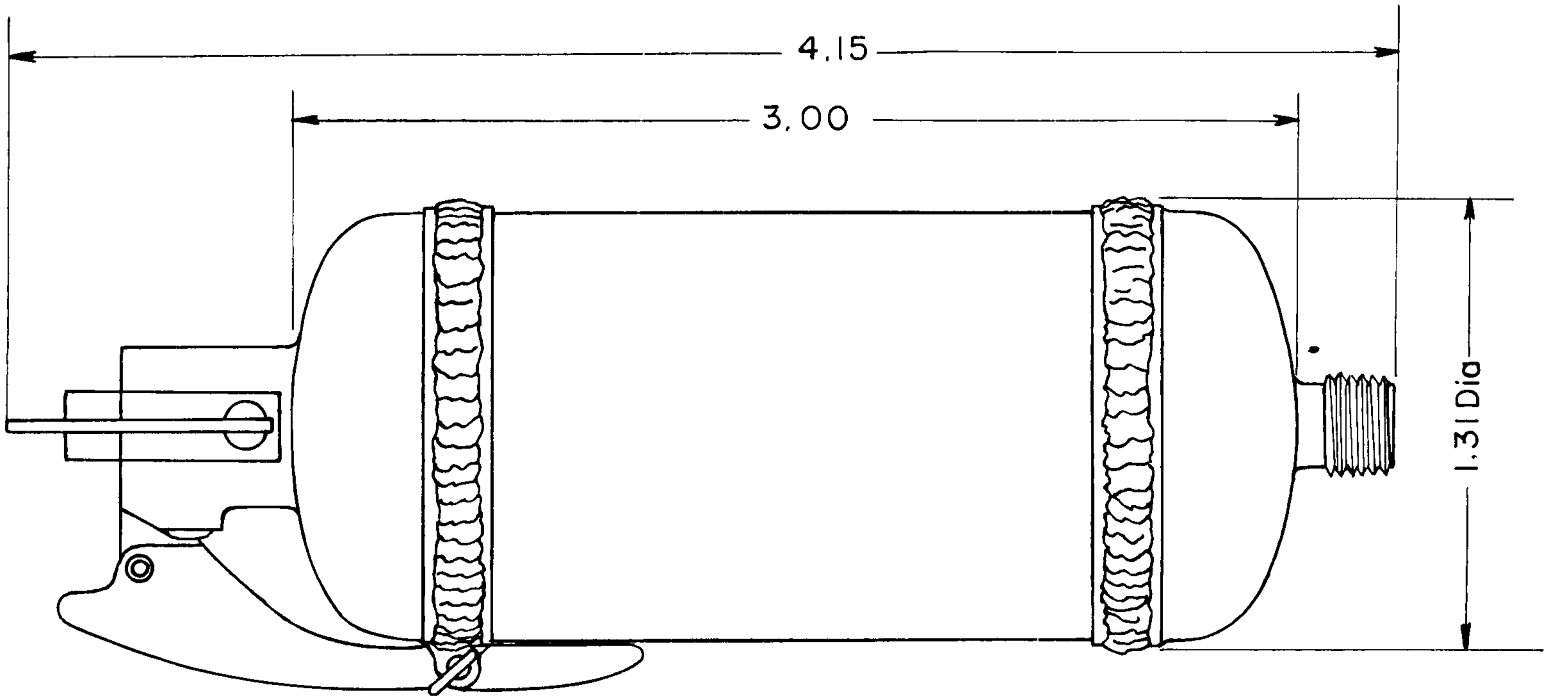


Figure 12.- External dimensions of pressure tank. All dimensions are in inches.

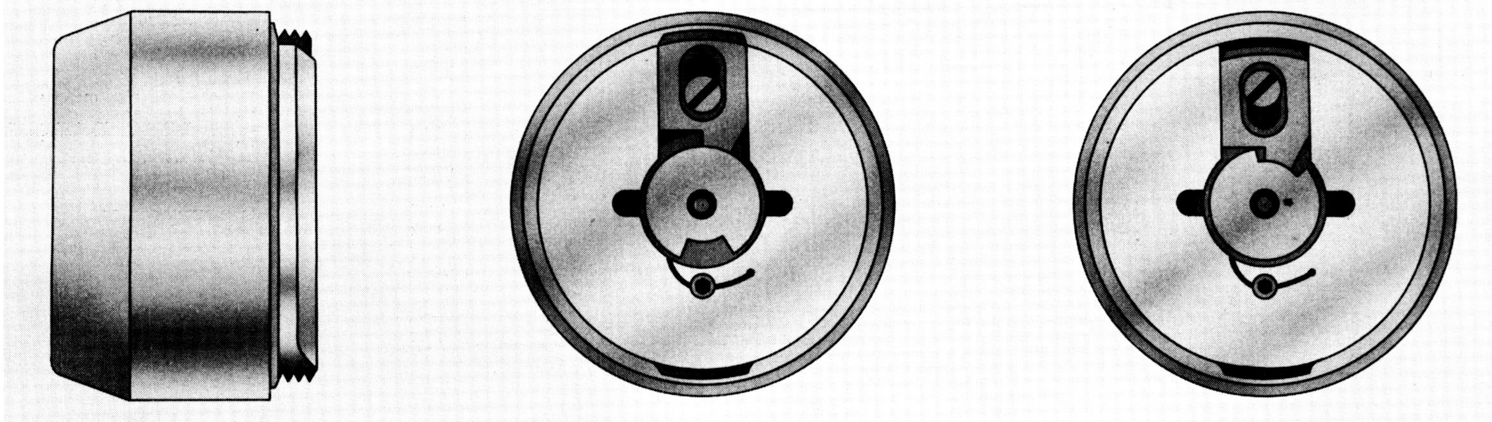


Figure 13.- Nose release mechanism.

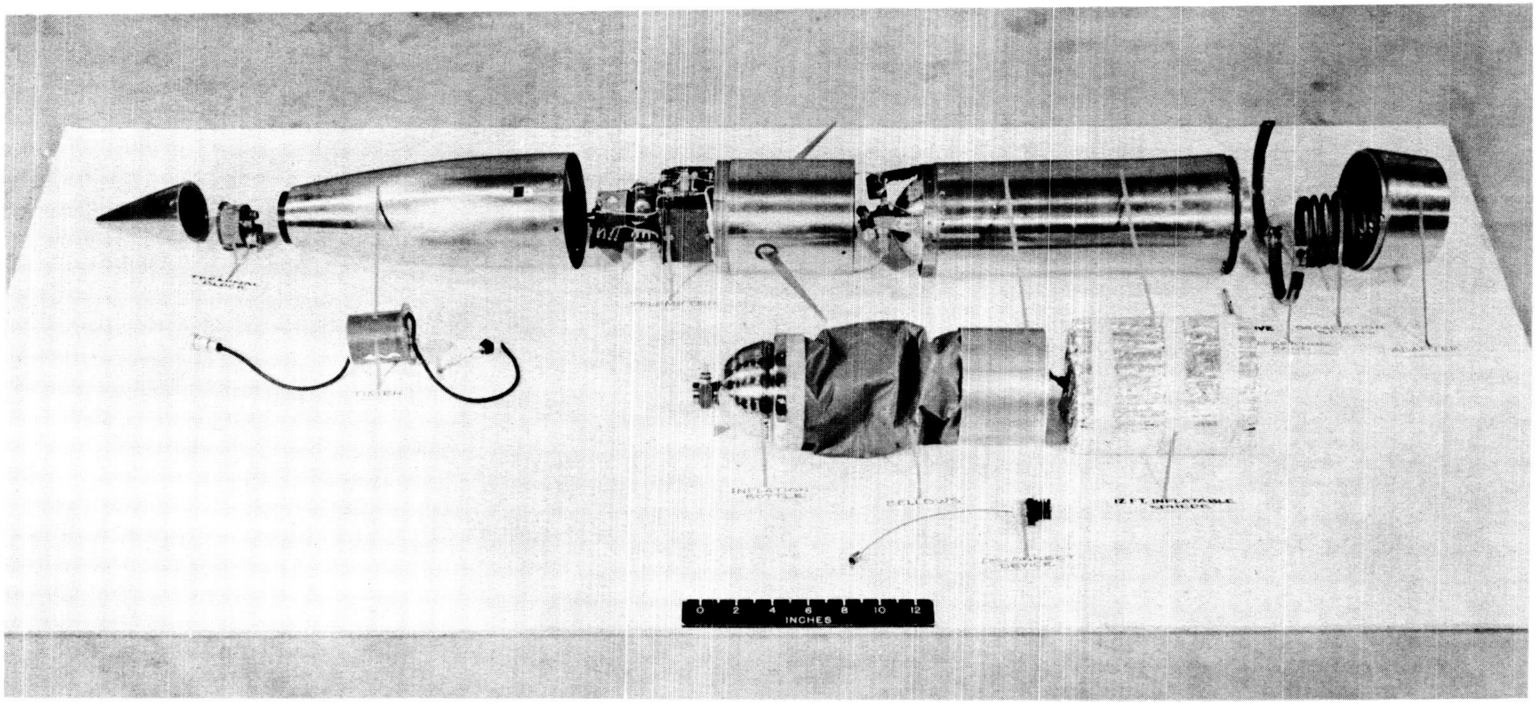


Figure 14.- Component parts of 12-foot radar test target nose section. L-59-718

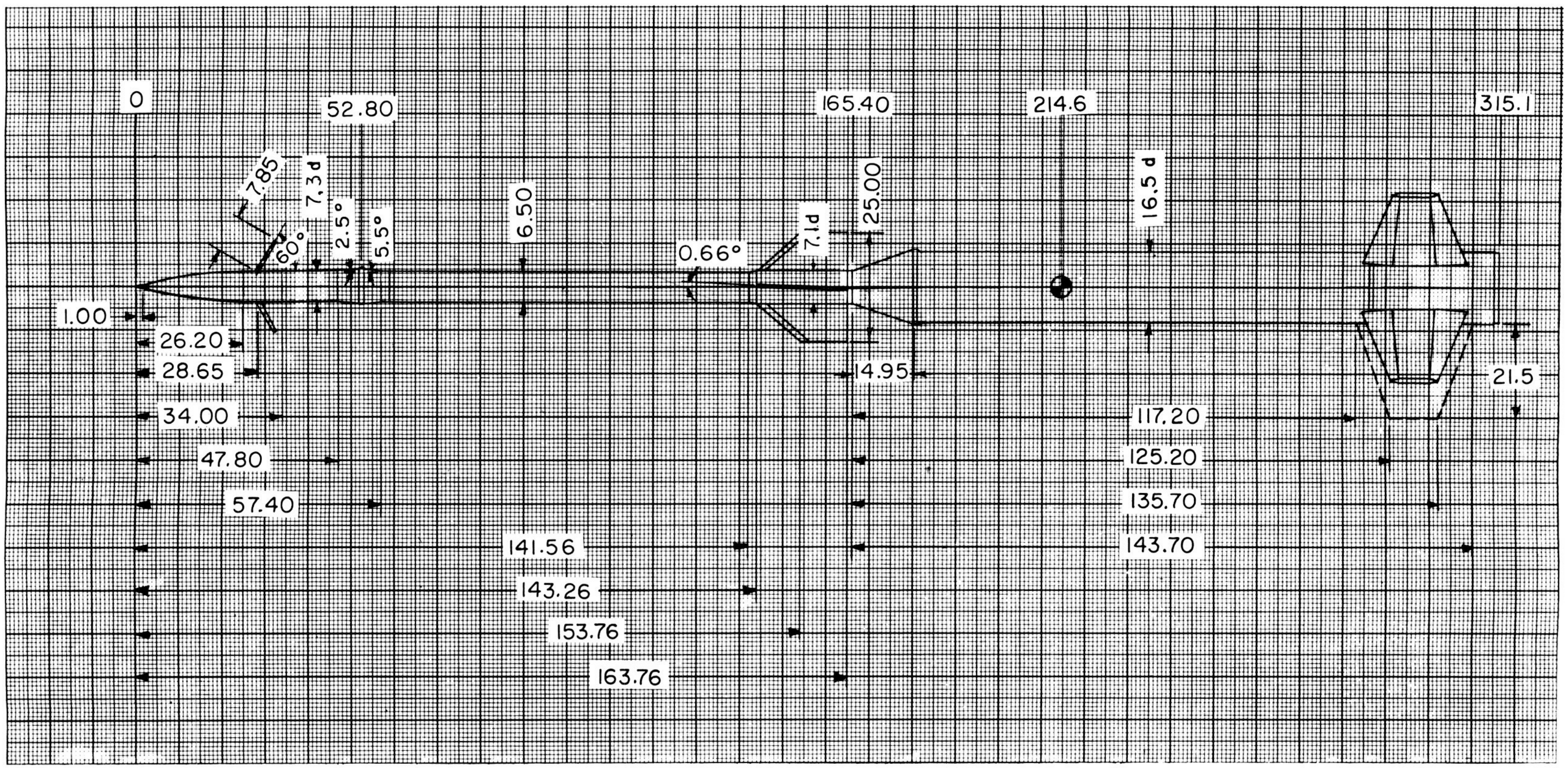
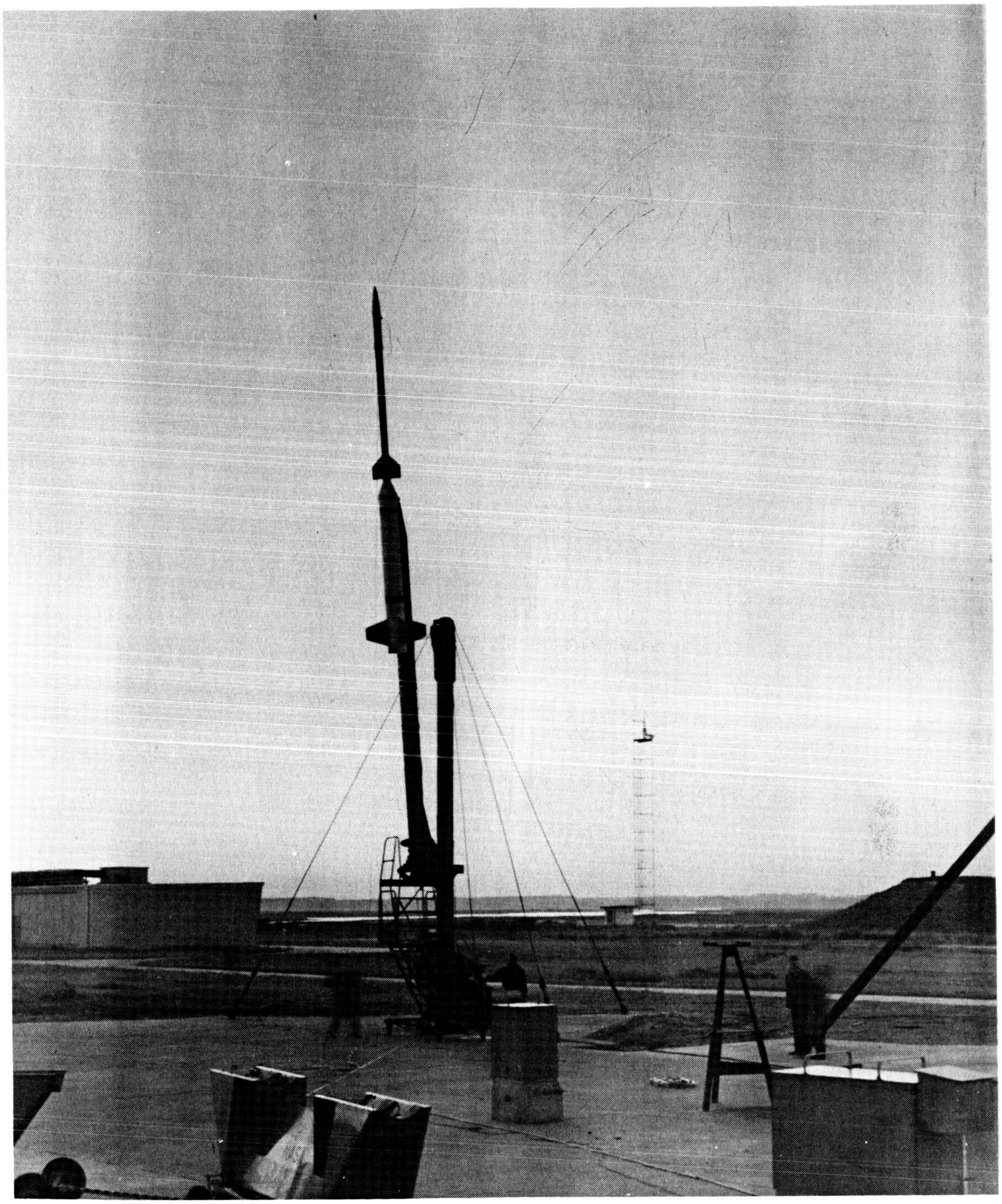


Figure 15.- General arrangement of rocket vehicle. All dimensions are in inches unless otherwise noted.



L-59-717
Figure 16.- The 12-foot radar test target system ready for launching.

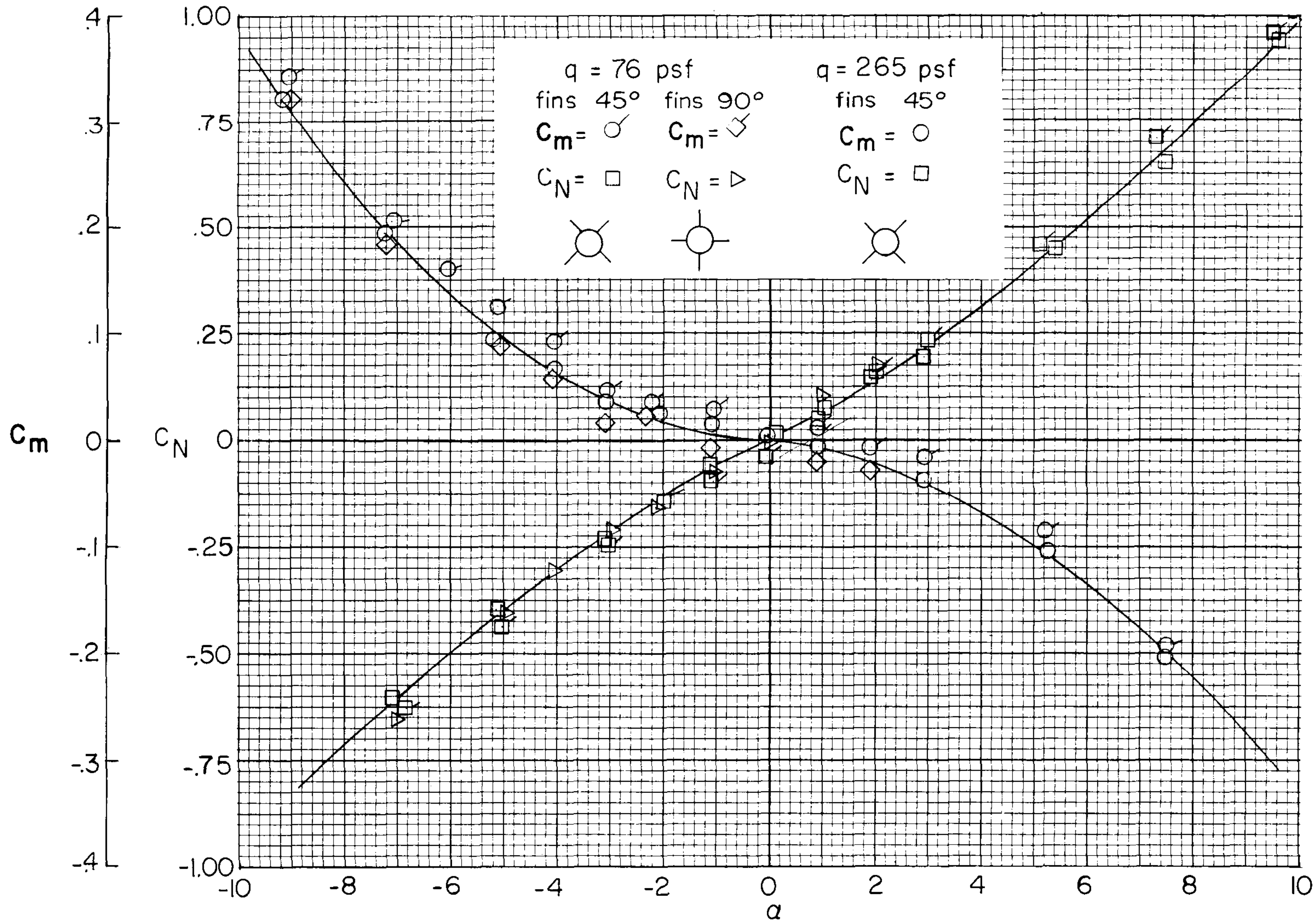


Figure 17.- Variation of normal-force and pitching-moment coefficients with angle of attack for plastic rocket.

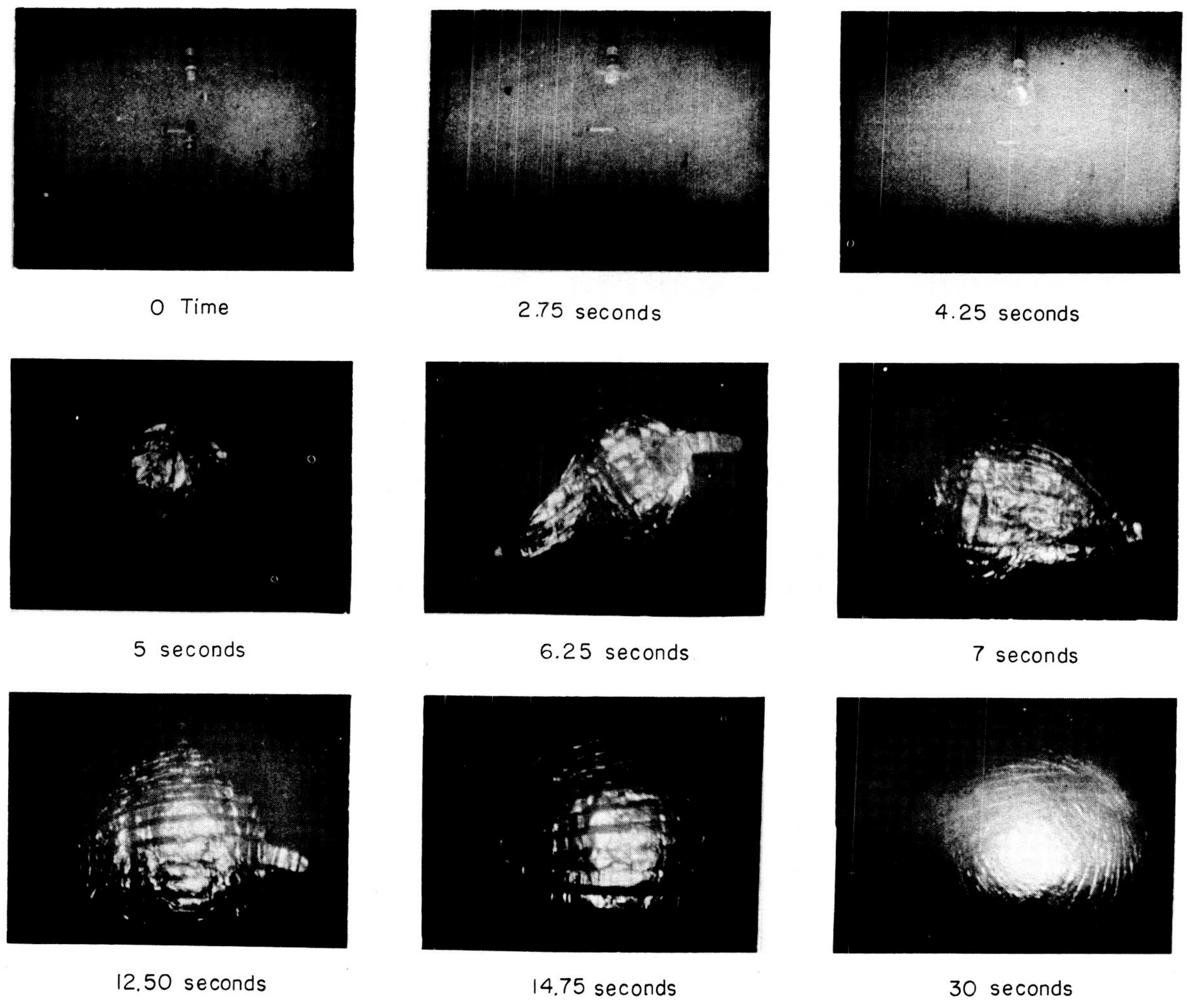


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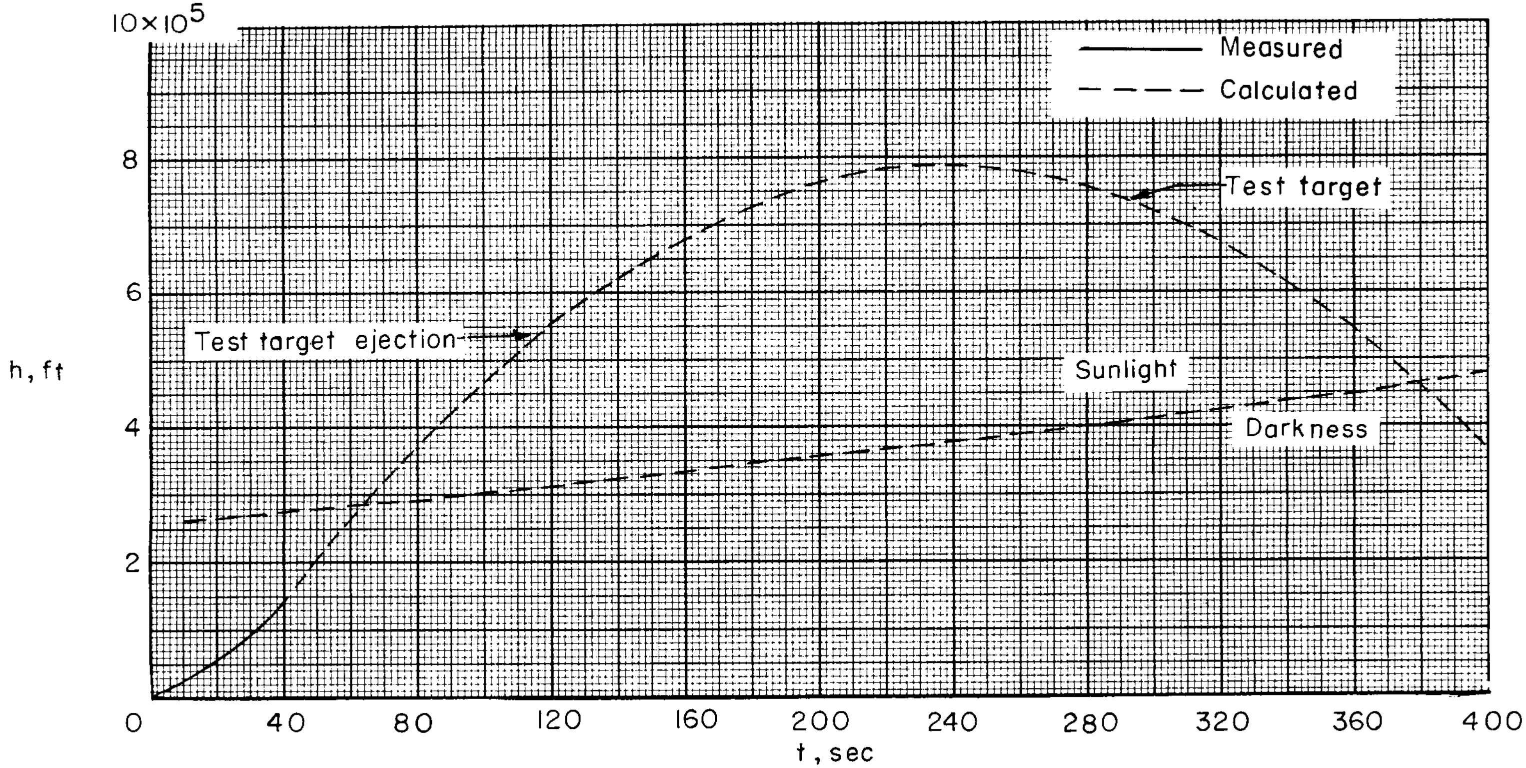
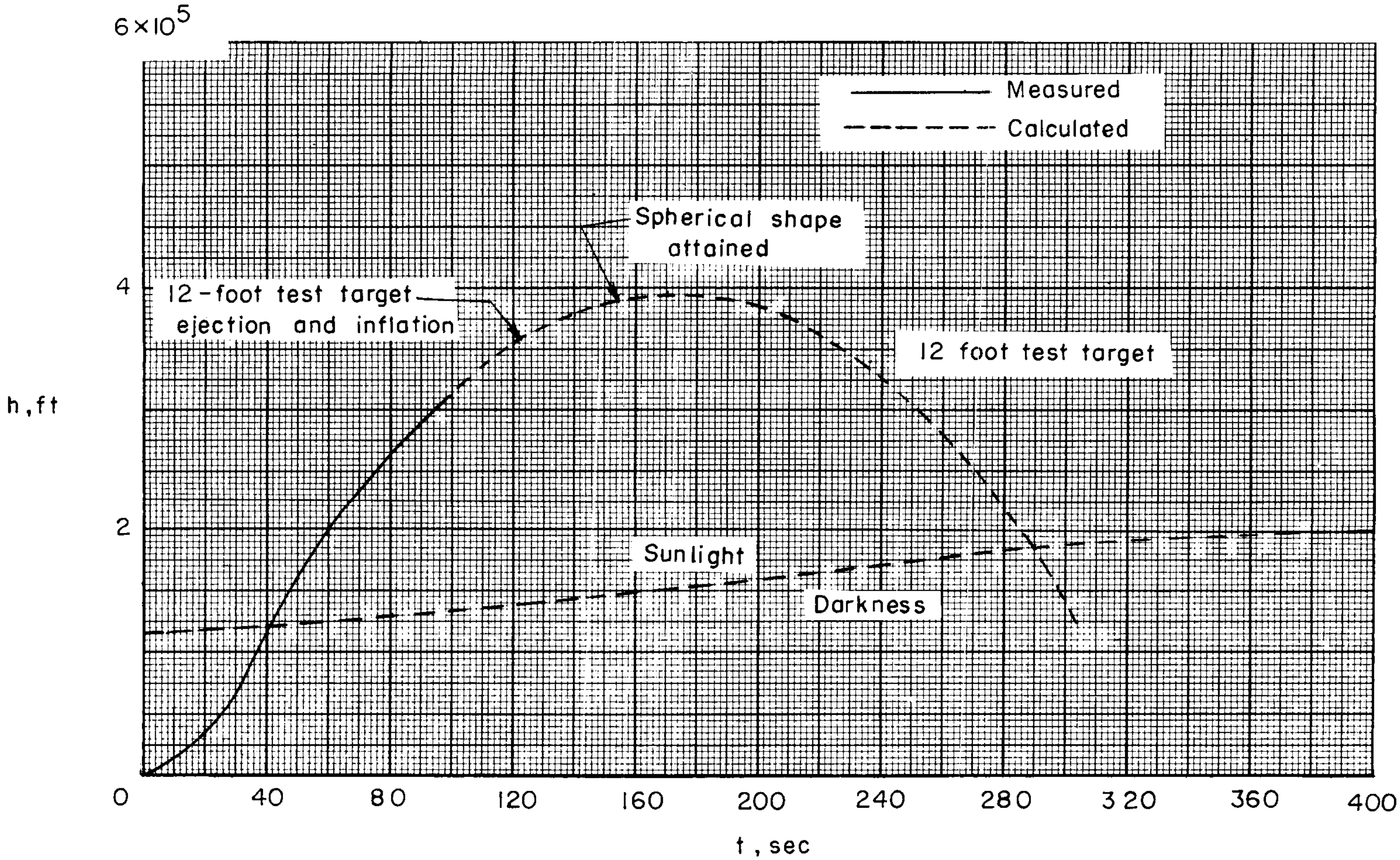
Figure 18.- The ejection and inflation of the 12-foot radar test target in the 41-foot vacuum sphere at specific time intervals.



(a) Time of altitude and darkness time in relation to the time history of altitude of 30-inch test target and Cajun booster.

Figure 19.- Altitude-time curves for 30-inch and 12-foot test targets.



(b) Time history of sunlight and darkness line in relation to time history of 12-foot test target altitude.

Figure 19.- Concluded.

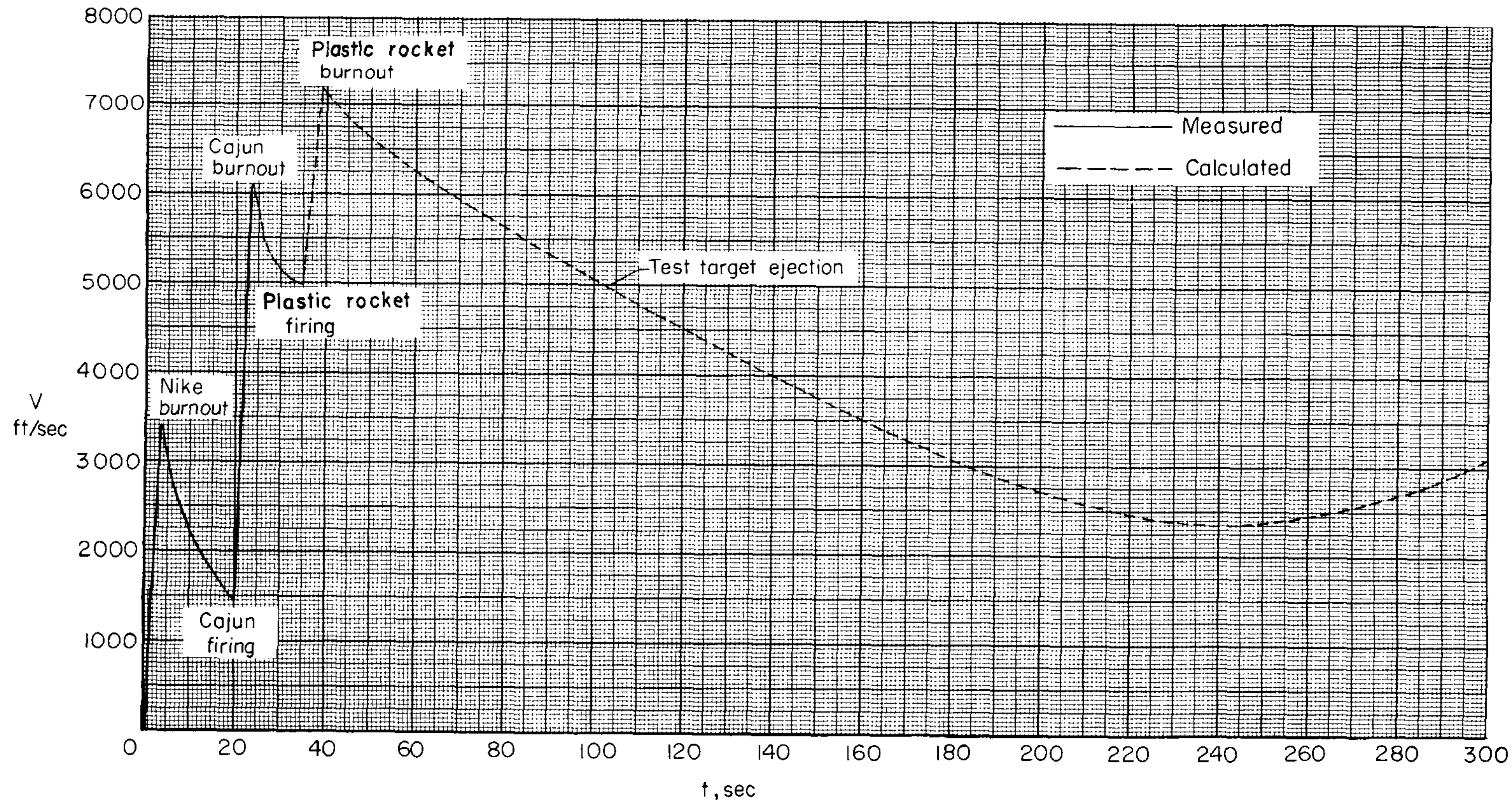


Figure 20.- Time history of velocity for 30-inch system.

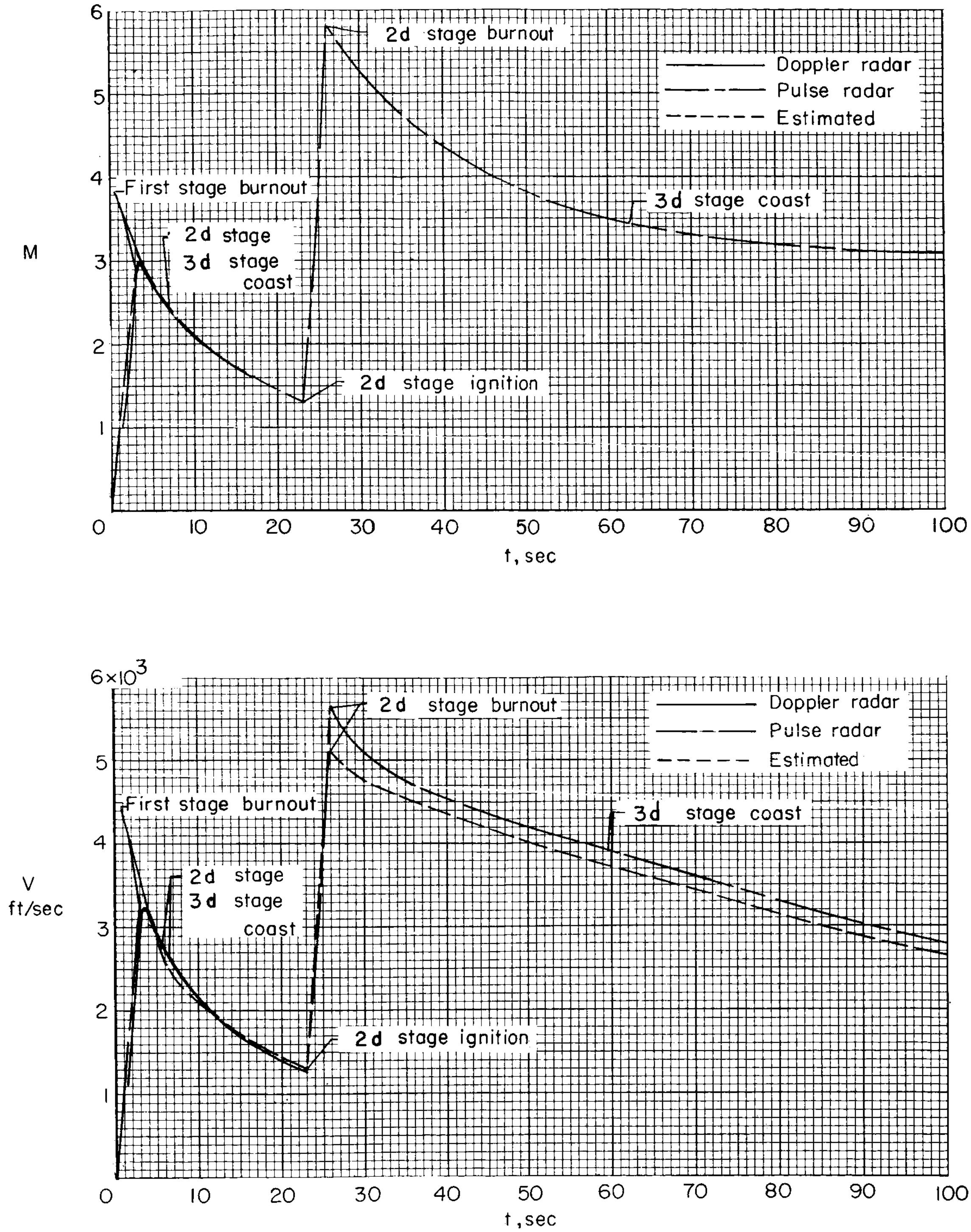


Figure 21.- Time history of velocity and Mach number for 12-foot system.

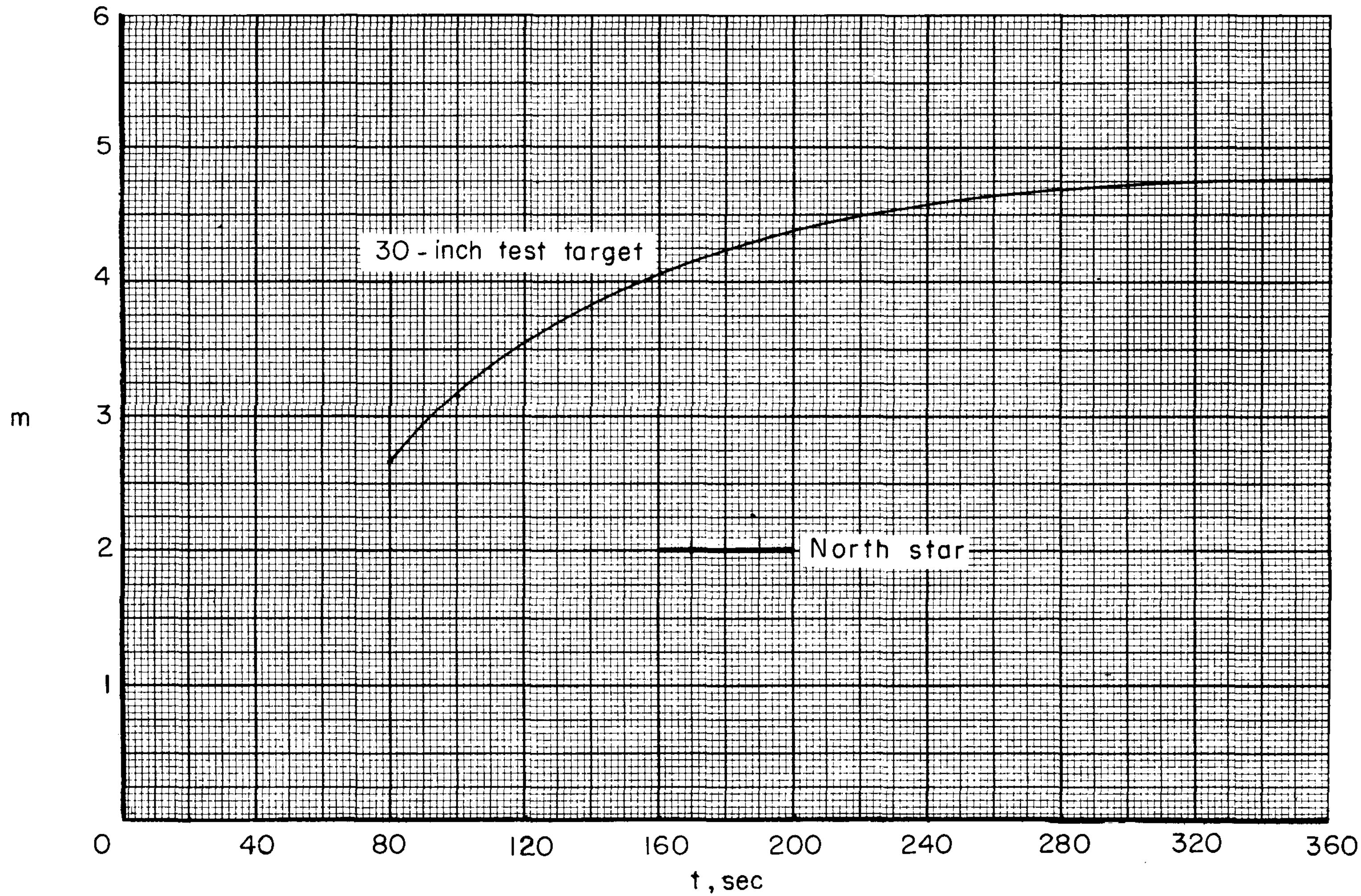


Figure 22.- Apparent magnitude as a function of time for 30-inch radar test target.

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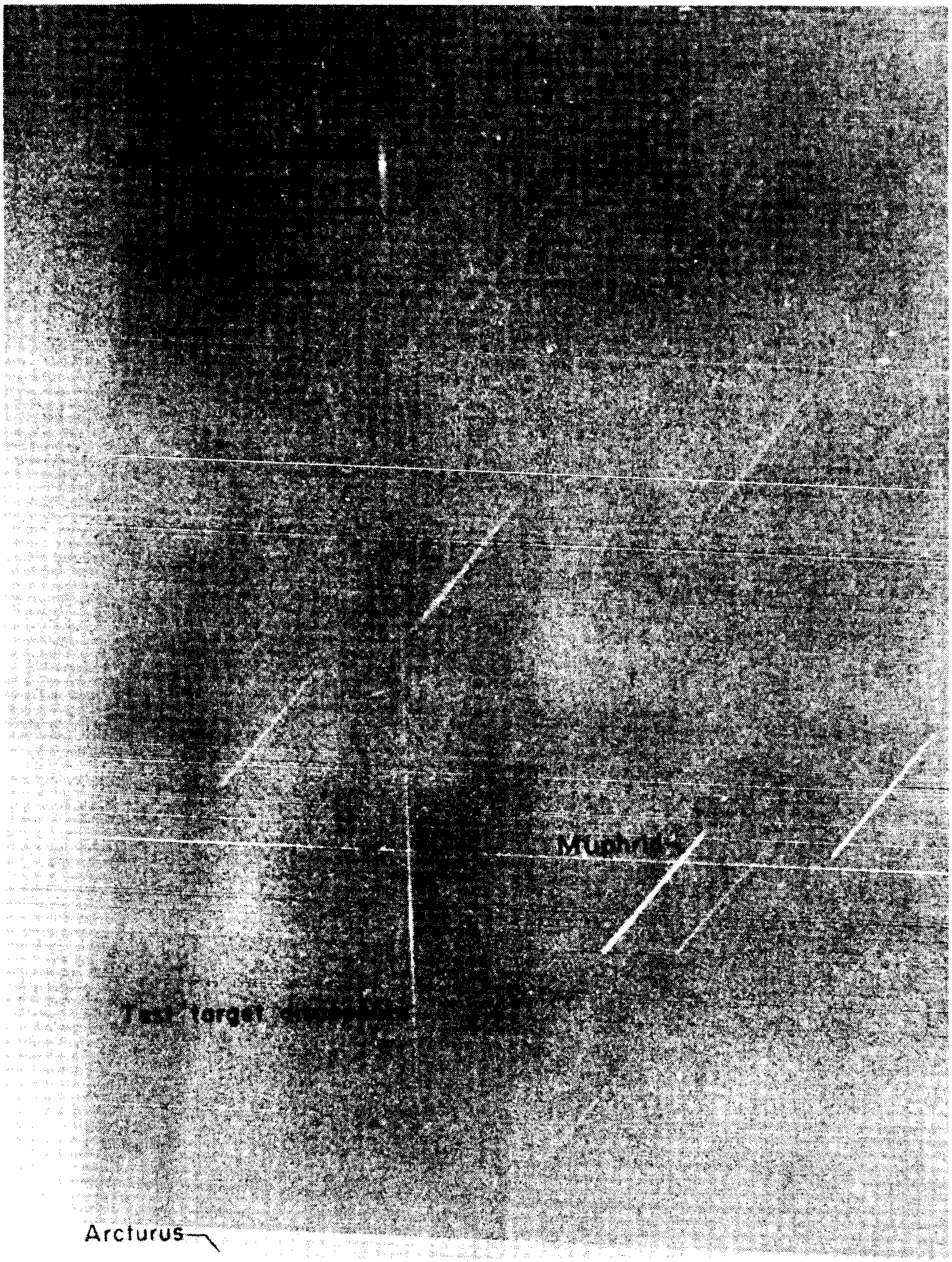

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Figure 23.- Time exposure of 30-inch test target against background of stars.

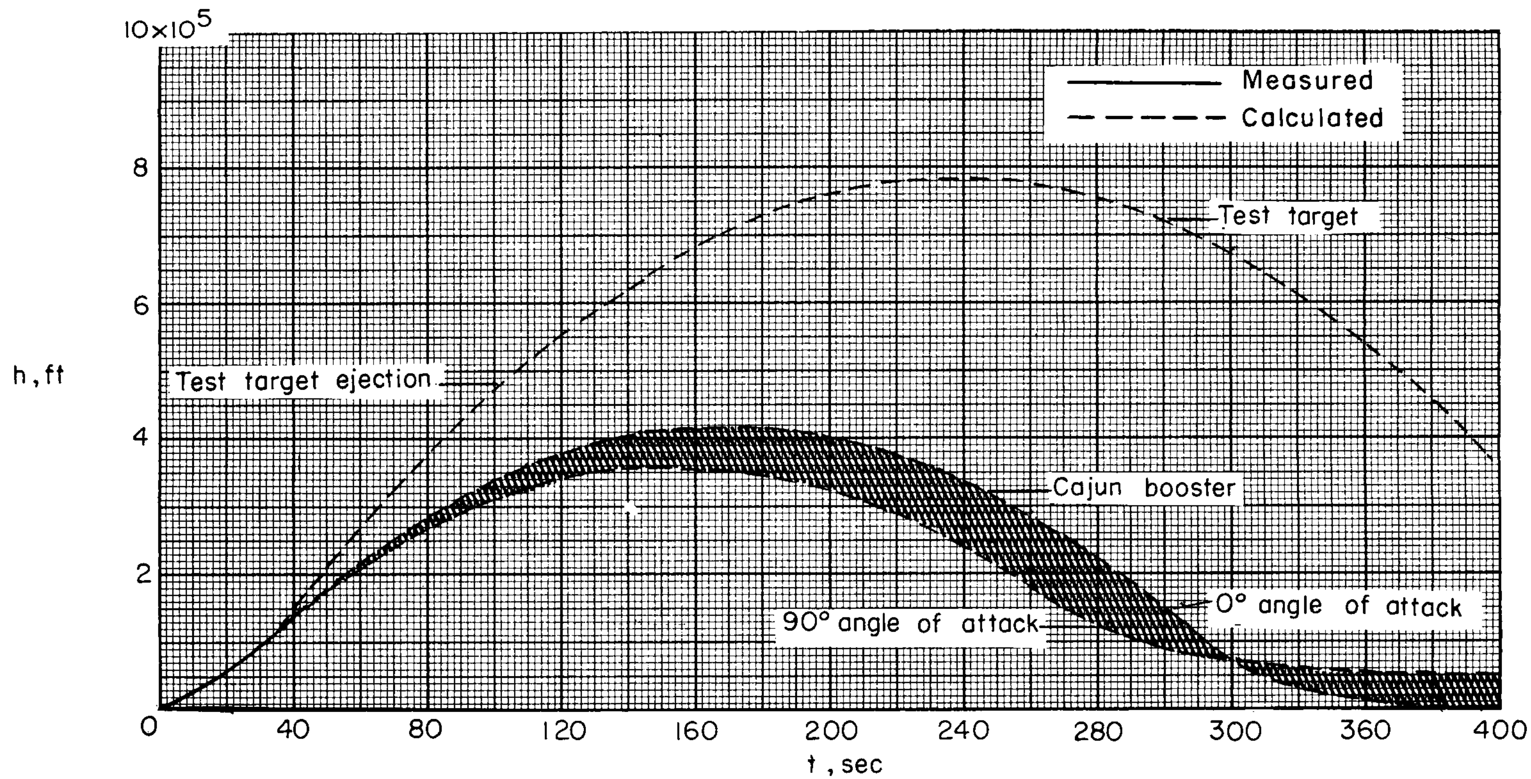

Figure 24.- Time history of altitude for test target and Cajun booster.

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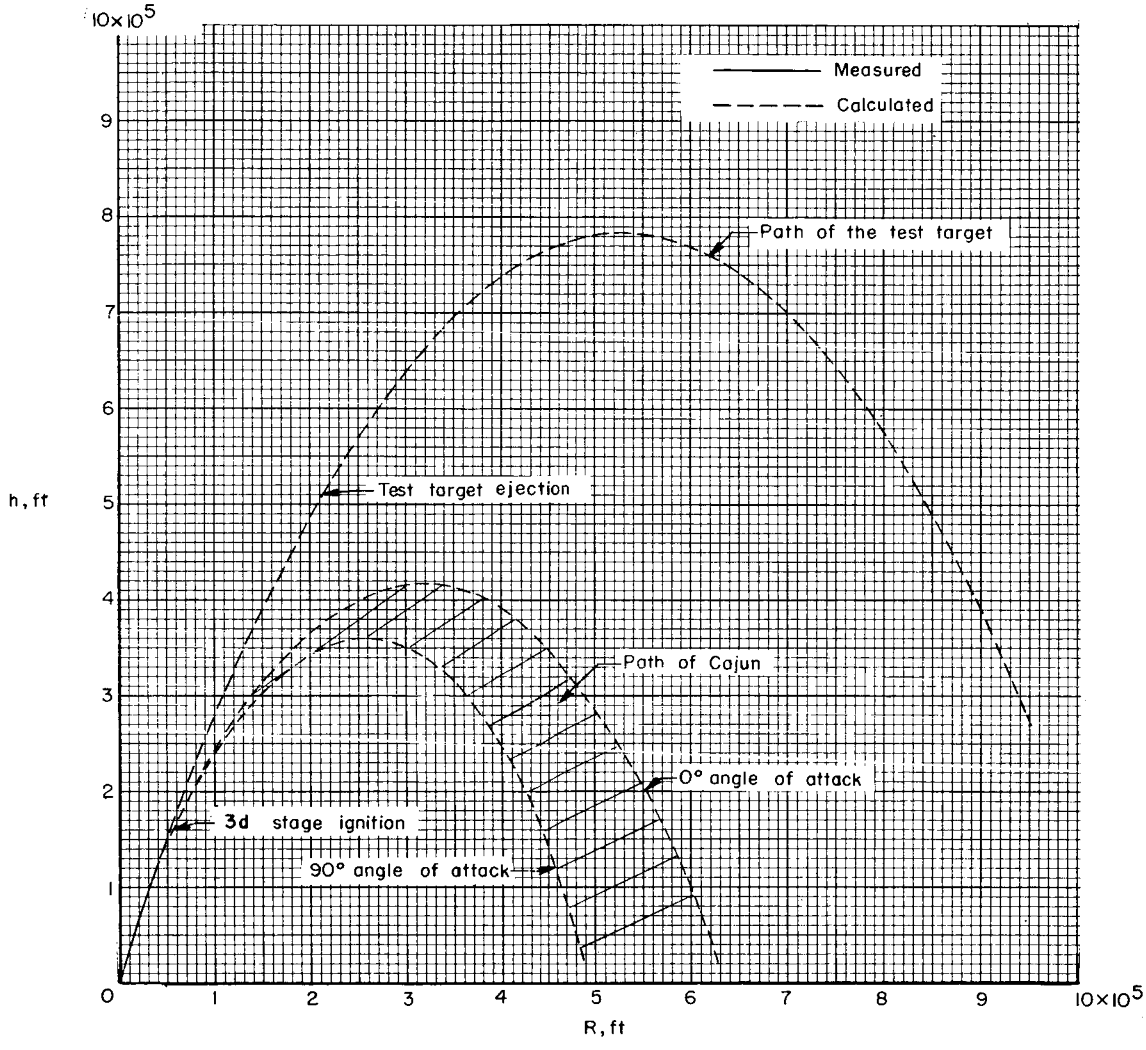

Figure 25.- Variation of altitude with horizontal range.

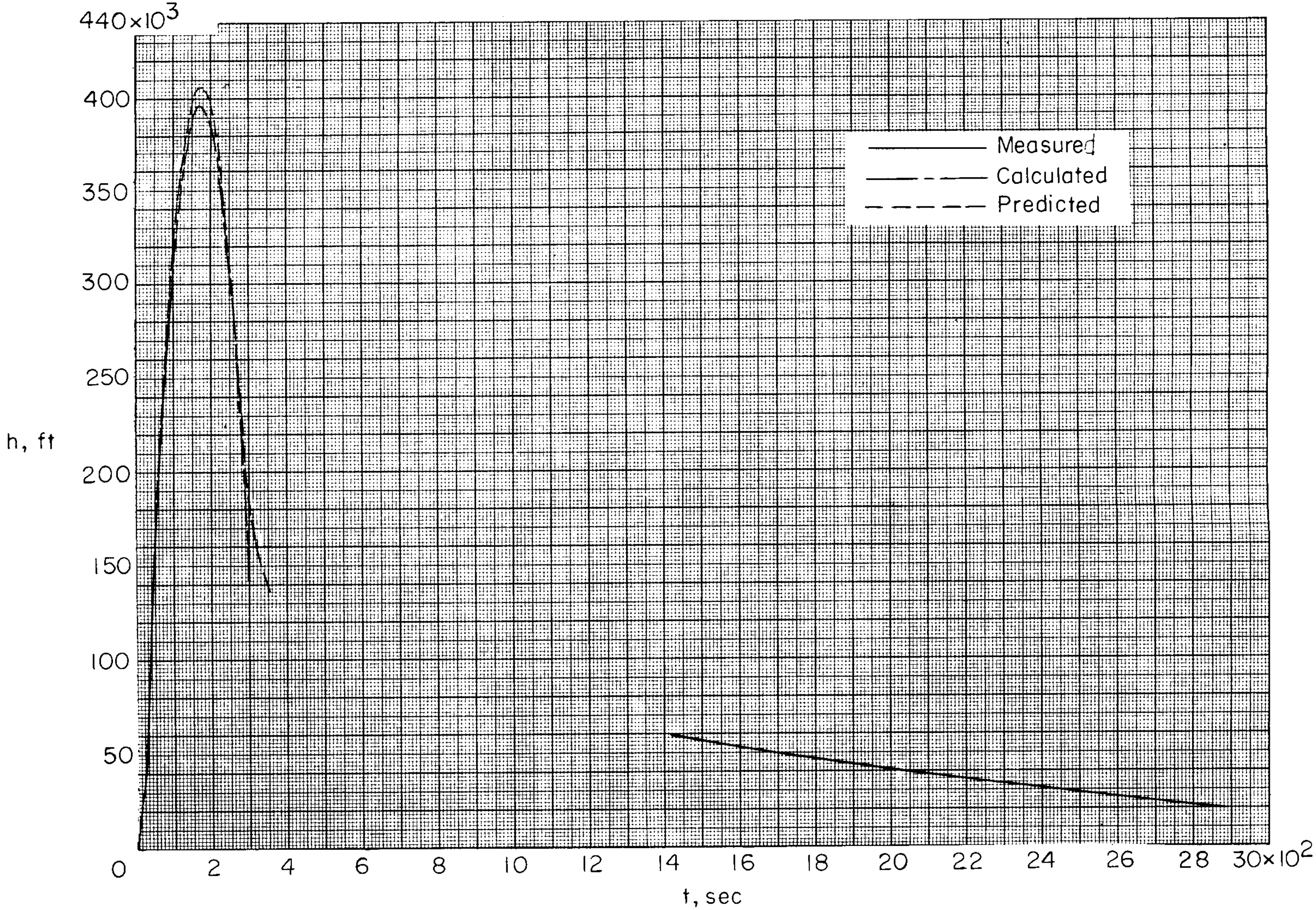

Figure 26.- Time history of altitude for 12-foot test target.

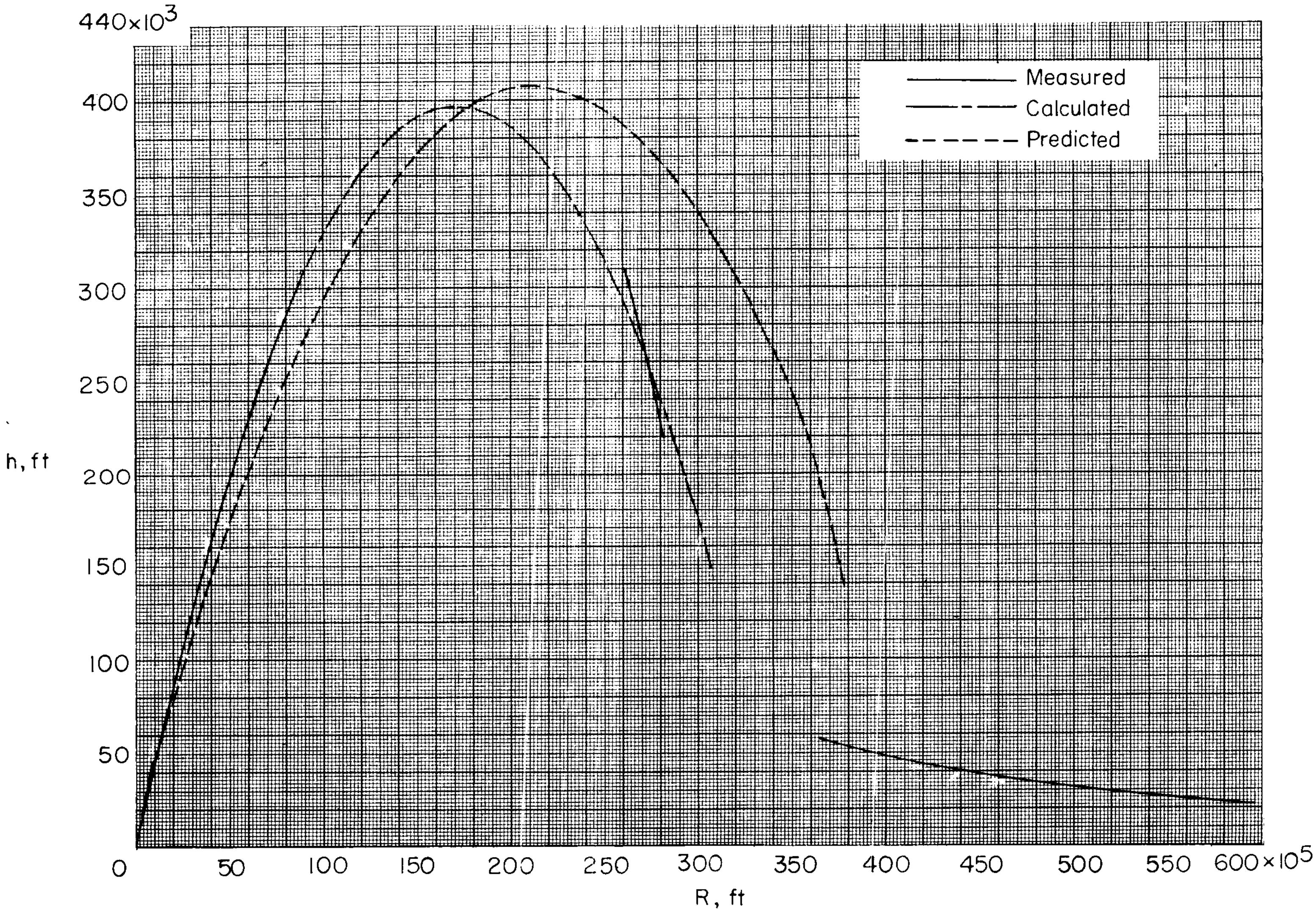

Figure 27.- Altitude as a function of horizontal range for 12-foot system.

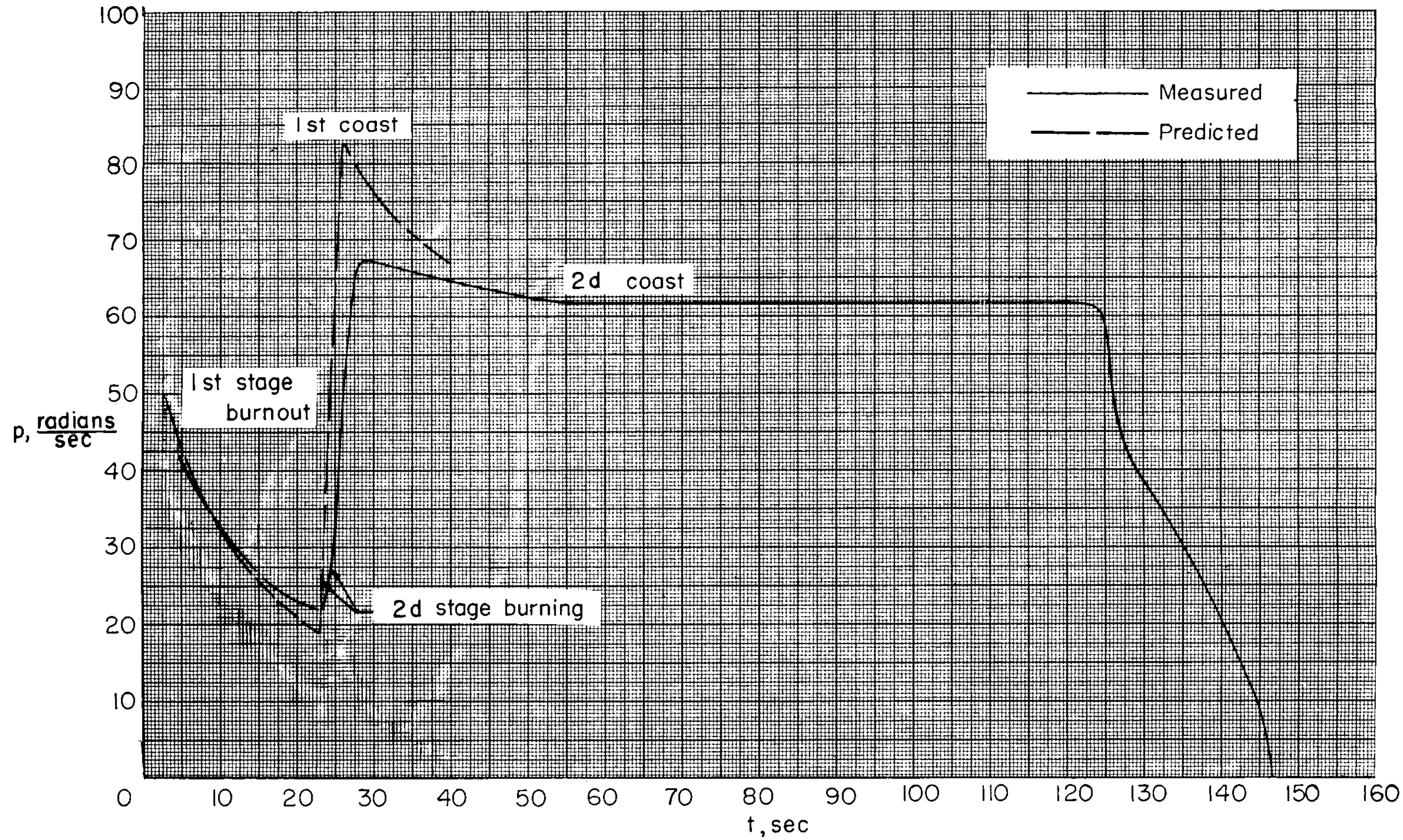

Figure 28.- Time history of roll rate of 12-foot test target system.

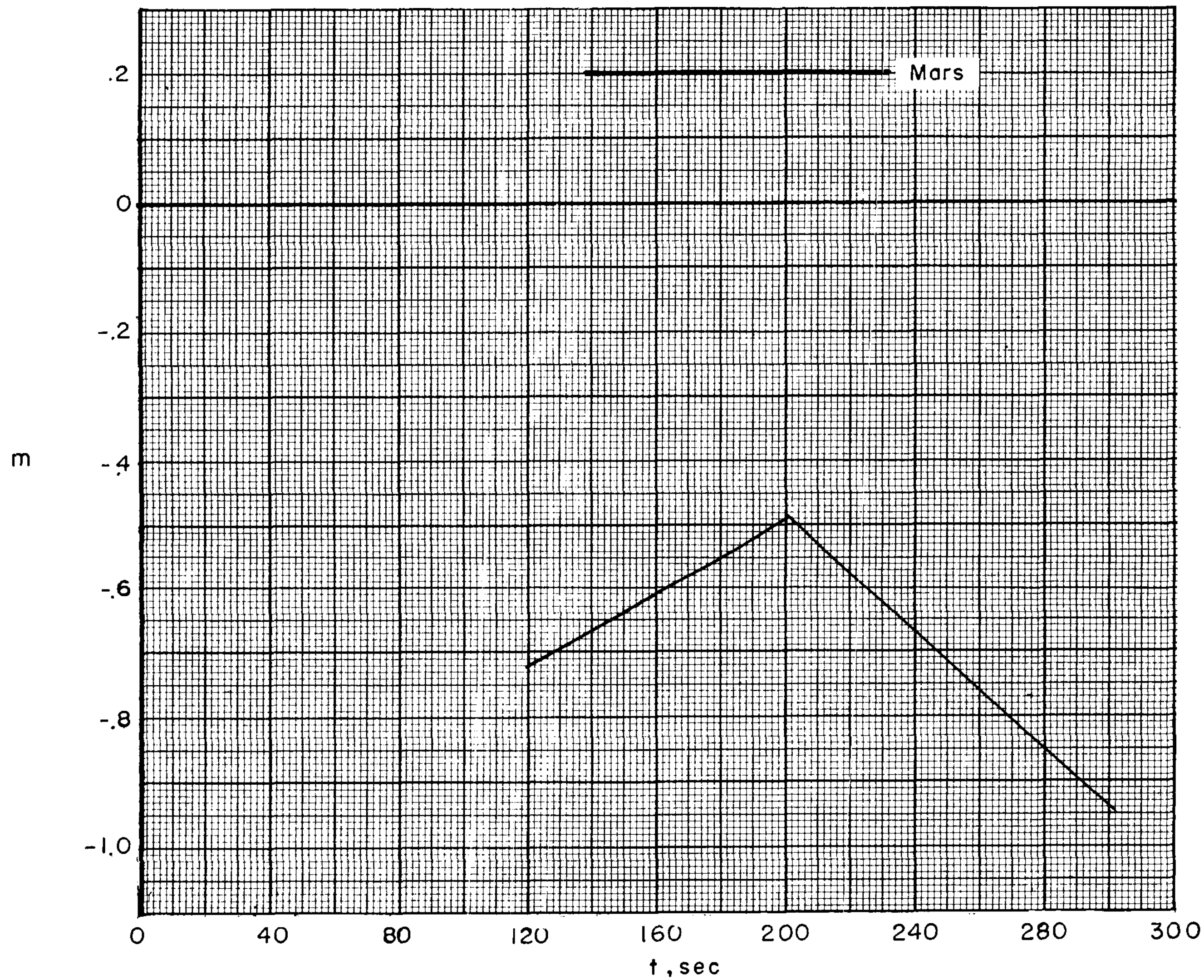

Figure 29.- Apparent visual magnitude as a function of time for 12-foot radar test target.

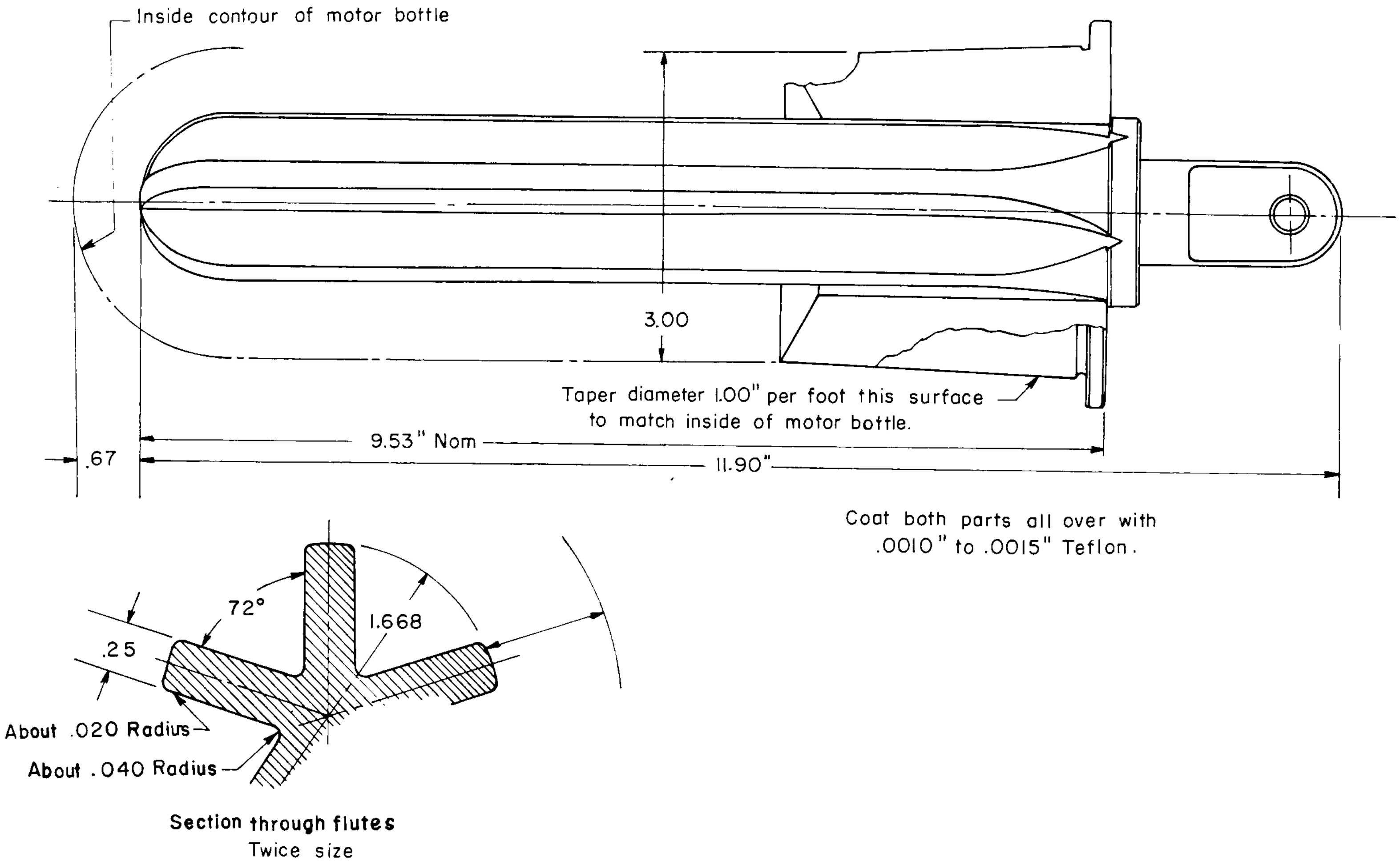

Figure 30.- Mandrel and flutes used for plastic rocket motor.

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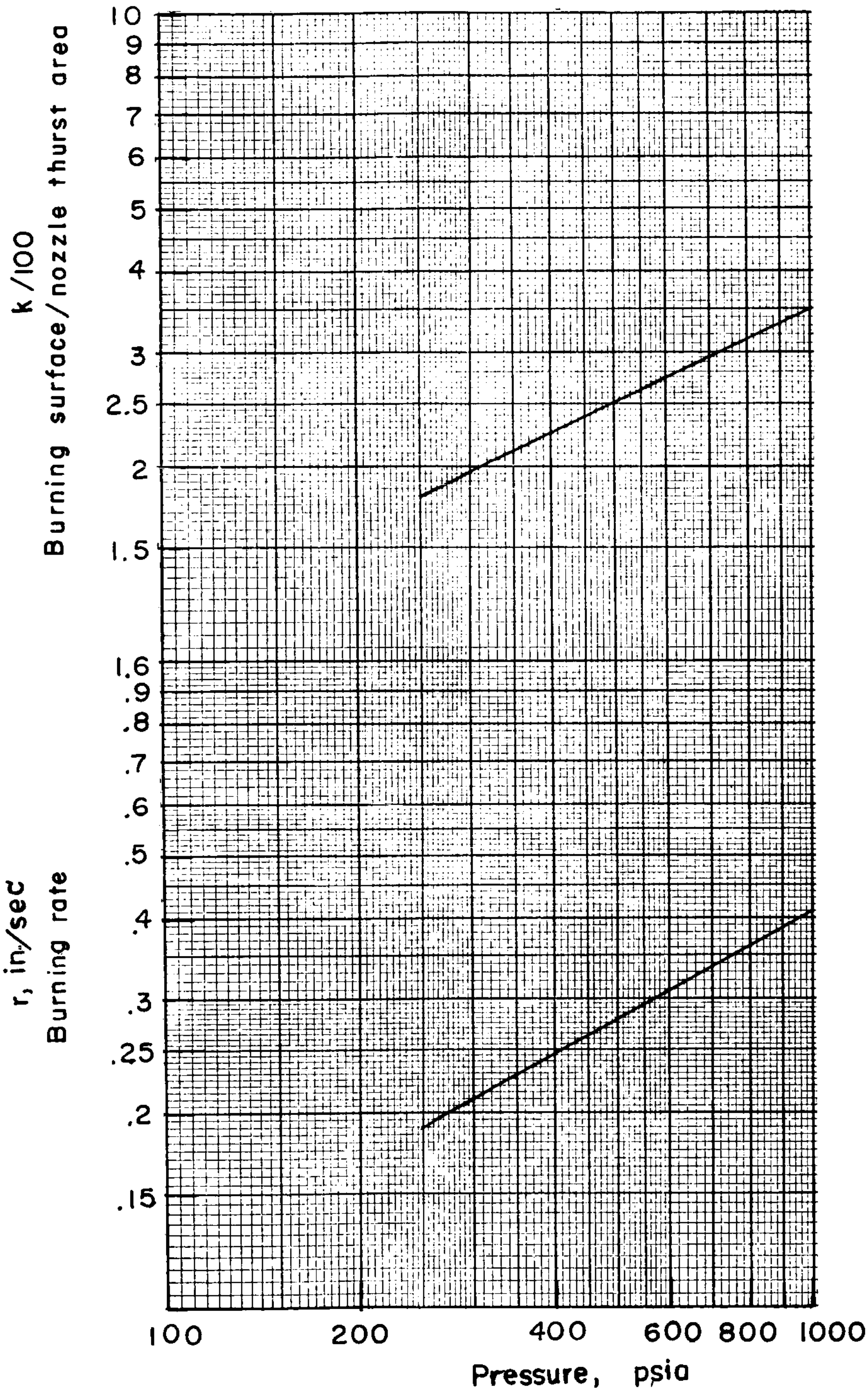

Figure 31.- Ratio of burning surface area to throat area and burning rate as function of pressure.

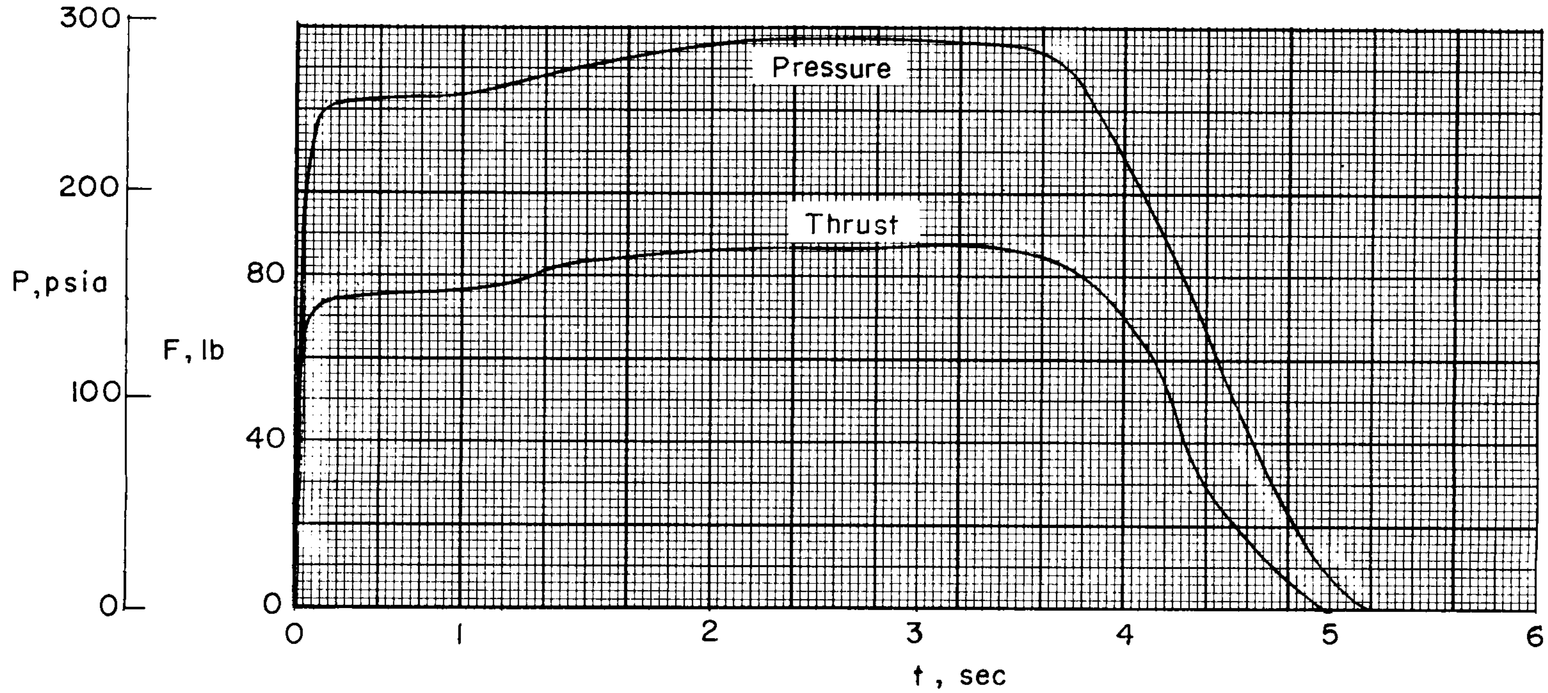

Figure 32.- Second static firing of plastic rocket.

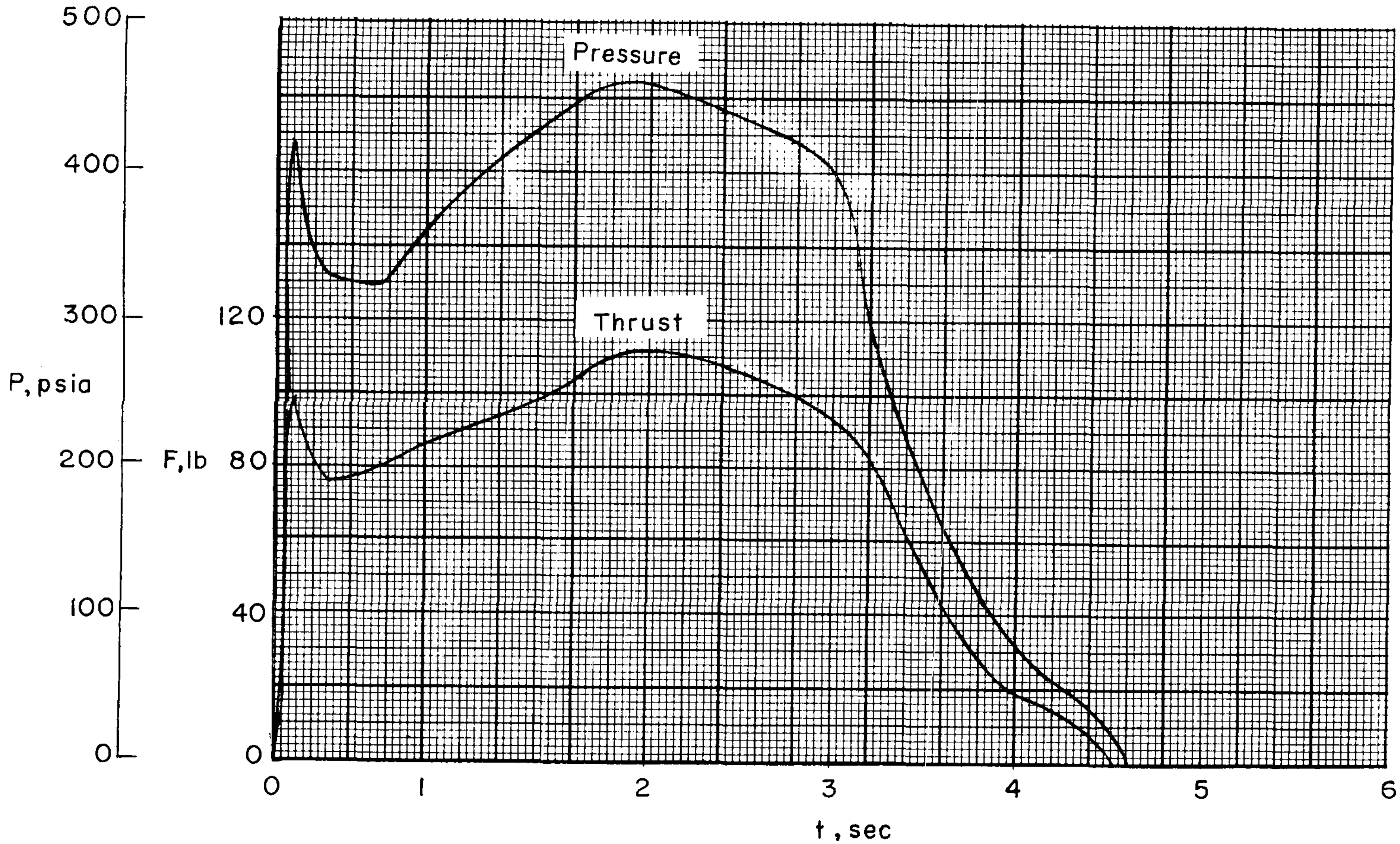

Figure 33.- Third static firing of plastic rocket.